Republic of South Africa

Development of a Framework for the Assessment of Wetland Ecological Integrity in South Africa

Phase 1: Situation Analysis

Department of Water Affairs and Forestry
Resource Quality Services

October: 2004

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EXECUTIVE SUMMARY

1. INTRODUCTION

This report is the outcome of Phase 1 of a Department of Water Affairs and Forestry (Directorate: Resource Quality Services) project to develop an integrated method for the assessment of wetland condition in South Africa. The three phases of the project are as follows:

Phase I	Situation Analysis
Phase II	Development of the integrity index
Phase III	Testing, refinement, implementation and evaluation of the assessment method.

The requirement for wetland assessment stems initially from an international and national focus on addressing the extensive global loss of wetland surface due to unsustainable growth and development. International agreements in this regard include the Ramsar Convention of 1971, to which SA is a signatory. The DWAF is mandated via the National Water Act (NWA, No.36 of 1998) to ensure conservation and protection of aquatic resources. The NWA requires that the environmental water requirements or the 'Ecological Reserve' be determined for all significant water resources in the country (including wetlands), and that Resource Quality Objectives be set for these systems. In the further development of the wetland Reserve Determination method to meet with this requirement, it is necessary to address the lack of a standard approach to the assessment of the ecological character and biological condition of wetland systems. Phase 1 of this study has focussed on developing a picture of what approaches have been taken and what protocols developed in this regard, both in South Africa and internationally. The project process has included an extensive literature review, and correspondence and consultation with wetland specialists, scientists and resource managers in SA and beyond.

2. APPROACHES, CONCEPTS AND DEFINITIONS

Ill-defined concepts and approaches in a scientific field can cause confusion. This chapter provides an insight into, and definition for, a number of terms, approaches and concepts relevant to the theme of the study. The definition used for wetlands is that documented in the NWA, rather than that of Ramsar which includes rivers and estuaries, amongst others. Over time, the approach to the classification of wetlands into different types and subtypes has evolved from that of the Cowardin system (based on natural physical characteristics) to a Hydrogeomorphic system (based on the similarity in functional properties of systems). For the purposes of this report (and potentially conflicting with DWAF's recently-published monitoring strategy) the view of a 3-way relationship between wetland inventory, assessment and monitoring is encouraged. Wetland inventory or mapping precedes the other two exercises and provides a basis for guiding appropriate assessment activities. 'Assessment' is taken to be the preliminary identification of wetland status and threats to present state. This provides the first-level information from which a 'monitoring' plan is devised. In wetland delineation, the outermost boundary of the wetland, which separates the system from adjacent terrestrial areas, is distinguished. The ecological character of a wetland refers to the structure and inter-relationships between the biological, physical and chemical components of a wetland. The reference condition of a wetland describes the characteristics of a wetland representing pre-impact state (or as close to this as possible).

3. BROAD APPROACHES TO ASSESSMENT OF WETLAND CONDITION

Three broad approaches to wetland evaluation are described. **Functional assessments** were developed principally for evaluating the potential impacts of developments which threaten wetland ecosystems by evaluating the change in wetland functioning over time. The purpose of biological assessment or **bioassessment** is to evaluate a wetland's ability to support and maintain a balanced, adaptive community of organisms having a species composition, diversity and functional organisation comparable with that of minimally disturbed wetlands within a region. Within an ecosystem evaluation framework, **habitat assessment** is often used alongside bioassessment, to provide information on the quality, quantity and suitability of the physical environment supporting the biota being measured. The use of these two approaches in tandem provides an effective means of interpreting data which may otherwise be misleading.

4. SOUTH AFRICAN WETLAND PROJECTS AND PROGRAMMES

A number of government departments, agencies and programmes have responsibilities regarding protection, management and wise use of wetlands in SA. Working for Wetlands is a national programme focussed on the rehabilitation of impaired wetlands in SA, using a capacity building and poverty-relief-driven platform. The programme is funded by National Treasury and is partnered by the Department of Environmental Affairs and Tourism (DEAT), DWAF, National Department of Agriculture, Working for Water and the Mondi Wetlands Project. According to Dini (pers.comm.), the partnership is formalised to the extent that a memorandum of agreement exists between DEAT and DWAF regarding Working for Wetlands, and there is a formally constituted Steering Committee, consisting of all the partners, with an approved Terms of Reference. By mid-2005 a formal memoranda of agreement should be in place with all the partners (Dini pers.comm.). The key projects underway through this organisation are the national wetland inventory, and an extensive research effort to develop wetland rehabilitation science and practice, in partnership with the Water Research Commission (WRC).

The Mondi Wetland Project (MWP) plays the role of catalysing the wise use and rehabilitation of wetlands in South Africa. It is a combined project of the World Wildlife Fund South Africa (WWFSA) and the Wildlife and Environment Society of South Africa (WESSA), together with two funders, the Mazda Wildlife Fund and Mondi Forestry. It is partnered by DWAF, provincial nature conservation and agriculture agencies, and the private sector. Current projects include the development and testing of WETLAND-ASSESS, a new functional assessment method for wetlands, incorporating a HGM classification system; and the development of a rapid, plant-based assessment system which is designed to assess wetland state and management requirements to achieve the desired state.

The WRC has a number of wetland research projects underway, many in partnership with other agencies, projects or programmes. These include a project to provide guidelines for the integration of wetlands into catchment management, an extensive project on wetland rehabilitation, a study to look at setting the water quality component for wetlands in the Reserve Determination process, and a strategic assessment to investigate the research needs for wetland health integrity (this includes a review of wetland assessment approaches worldwide and in SA). **It is recommended that the DWAF and WRC ensure linkage between their separate initiatives regarding the assessment of wetland condition.**

The DWAF's role in wetlands is not yet extensive, however the Department has produced a protocol for the delineation of wetlands in SA. Of further interest to this programme is also the DWAF Strategic Framework for National Water Resource Quality Monitoring Programmes (2004).

5. INTERNATIONAL APPROACHES TO WETLAND ASSESSMENT

The focus in this chapter is on three international areas: the Ramsar Convention, the USA and Australia. Ramsar's approach to wetland assessment provides emphasis on guidelines for risk assessment, for predicting and assessing change in the ecological character of wetlands.The 6-step method requires an identification of problems, adverse effects, the extent of the problem, and the risks. These concerns are addressed through risk management and reduction, and outcomes of this process are monitored.

In the USA, the key agencies involved in wetland assessment are the US Army Corps, the US Environmental Protection Agency (US EPA), the US Geological Survey (USGS) and the US Fish and Wildlife Service (USFWS). The focus in this chapter is on the outcomes of intensive decades of development of methods to assess the effect of developments on wetland functions, to fulfil the requirements of Section 404 of the Clean Water Act. Over 40 methods for the assessment of wetland function exist. The field of bioassessment is relatively new in the US. This is, however, characterised by an enthusiastic development of multimetric approaches modelled on the Index of Biological Integrity (IBI) approach of Karr (1981). The biota used in assessment include amphibians, vascular plants, macroinvertebrates, algae/diatoms, birds and – to a lesser extent - fish.

Australia is in the process of fulfilling the objectives of its National Wetlands Policy, one of which is to monitor the state of wetland and provide Sate of Environment reporting on the extent and condition of wetland resources. None of the states had a wetland monitoring programme by 2003 (this situation may now be different). There was, however, a New South Wales-based programme focussed on monitoring the outcomes of environmental flow allocations to wetlands. In Western Australia, an rapid assessment technique based on invertebrate sensitivities (linked to environmental data) has been trialled in coastal wetlands.

In Asia, a framework for a Wetland Inventory, Assessment and Monitoring System (WIAMS) has been developed. This approach merits some examination and consideration for South Africa. In the Mediterranean, MedWet is an initiative aimed at the inventorising of wetlands, and the development of methods to improve wetland management and halt further wetland degradation.

6. VARIABLES USED IN THE ASSESSMENT OF WETLAND CONDITION

Three groups of variables are commonly used in wetland assessment: functional, physical and biotic. Soil is one of the most important of the physical variables, and its use as an indicator of the wetting regime in wetlands is described hereinafter. Following this, this chapter examines a number of biotic variables as indicators of wetland condition, describes their role in wetlands, their value as indicators, and provides a series of methods associated with each. The variables considered are: plants, algae and diatoms; aquatic macroinvertebrates; fish; amphibians and birds.

In South Africa, wetland **vegetation** is the component of the biota that is best known and understood. Plants, being highly sensitive to hydrology, are commonly used to delineate wetland boundaries. They are regarded as one of the best indicators of the factors that shape wetlands within a landscape. Clear relationships have been demonstrated between changes in wetland plant community composition and a suite of wetland stressors, including hydrologic alterations, nutrient enrichment, sediment loading, turbidity, metals and other pollutants. Community composition is however also affected by natural disturbances, which can complicate the interpretation of plant data.

On the whole, however, there is strong support internationally for the use of vegetation (particulary vascular plants) in wetland assessment. An extensive array of metrics have also been developed for the vegetation of different wetland types. A number of indices of biological integrity have been developed in the US for this purpose. One of these, the Index of Plant Community Integrity (IPCI) was developed with the intention of linking to the HGM functional assessment protocol. This approach of combining functional and biological assessment warrants further attention in SA.

Algae play an essential role in nutrient and energy cycling, habitat provision, and serve as a foodsource to invertebrates and small fish. Algae and diatoms are gaining increasing popularity in water quality assessment worldwide. The algal IBI reviewed reported that algal indicators demonstrated a relationship with human disturbance variables, nutrient enrichment, Total Phosphorus, Total Nitrogen and Chlorophyll a. In South Africa, there is little research attention being directed towards algal studies.

Diatoms, because of their siliceous cell walls (frustules) are of particular value in evaluating the historic spatial extent of wetland ecosystems. They are also used as indicators of water quality. A South African research team, based at the University of Potchefstroom, is currently testing a French diatom index, the Specific Pollution Sensitivity Index (SPI) in aquatic ecosystems. In rivers, the SPI index has (in some, but not all cases) been shown to correlate positively with pH and negatively with conductivity, Chloride, and Ammonium.

Invertebrates are an important (and lesser known) component of wetland food webs, both as a food source to fish, water birds and other wildlife, and in consuming algae, detritus, plants and other prey organisms. They play an integral role in the recycling of nutrients and energy transfer. Wetland invertebrates differ from stream invertebrates in their greater tolerance of low dissolved oxygen concentrations. They are found in virtually all wetlands.

Internationally, aquatic macroinvertebrates emerge as the next most popular variable in use in wetland assessment. This is counter-intuitive in many ways, as the high hydrological variability in wetlands (and thus habitat) over both time and space would seem to make a case against this group as a reliable indicator of non-natural change. A number of IBI-type indices have been developed in the US based on macroinvertebrates. Metrics within these IBIs have been selected on the basis of demonstrating change in value along a gradient of human disturbance. Significant relationships have been also been demonstrated between IBI scores and water quality parameters, including turbidity, Chloride and Phosphorus. In Australia a sensitivity index, along similar lines to the SA Scoring System vs 5 (SASS5) index used in SA, have been developed for coastal plain wetlands.

The **fish** of most wetland ecosystems (except lakes and floodplains) have not been widely studied, and this group is not in common use in wetland condition assessment. Surprisingly little has been done to develop IBIs for fish (particularly those of non-tidal wetlands). One fish IBI trialled on lacustrine wetlands in Florida (US) showed increasing scores with increasing nutrient levels and lake area. Fish metrics tested for their value as indicators in medium-sized floodplain wetlands in Minnesota did not show consistent patterns.

Amphibians represent a link between the wetland and the surrounding landscape. They are especially vulnerable to alteration or pollution of wetlands. One motivation for studying this group has been the concern over their declining populations worldwide. Amphibians are not well known as a monitoring tool, and only one IBI was reported from Ohio, which suggested that the group was promising as a braod indicator of wetland condition. The constraints include the variability of amphibian populations within hydrologically and hydraulically variable environments, which wetlands are known to be. In South Africa, the eggs and tadpoles of the frog *Xenopus laevis* have been shown to be successful bioindicators of acidic waters, and of the presence of particular heavy metals. This has been tested in streams, but not yet in wetlands. Amphibian specialists have also expressed interest and support for the use of audio recordings of frog calls in inundated wetland environments to identify species presence, and to use this information to develop a broad *Actual / Expected* rating for frog diversity. Another relatively simple index of diversity would be a comparison by specialists between the diversity of frog species present in a natural wetland, versus the diversity of species present in an impacted wetland with similar hydrology, morphology and call sites. Individual frog species are tightly linked to "call sites" (characteristic micro-environments from which the species will call), and this information could be used by a specialist to determine "call site utilisation". *Despite the clear opportunity presented by amphibians, because of the variability associated with this group, it has been suggested that at least 5 years of monitoring or data per wetland system would be required to use amphibian data to develop wetland ratings at any level of precision.*

Waterbirds have attracted the most attention of all the wetland biota, and protection of their wetland habitat was one of the primary focus areas for the Ramsar Convention on Wetlands in 1971. As indicators, birds may detect aspects of wetland landscape condition that are not detected by other indicator groups – particularly the connectivity between wetlands at large spatial scales. Many nationally and internationally important wetland sites have been listed on the basis of the bird species occurring there. The development of IBIs for birds is in its infancy in the US, but is considered to hold great promise. International authors suggest that research should be focussed on spatial changes in bird communities across a suite of wetlands that reflect a gradient of human disturbance, to establish which groups are suitable indicators of wetland condition, and at what scales.

7. THE ROLE OF ASSESSMENT IN THE DETERMINATION OF WETLAND ENVIRONMENTAL WATER REQUIREMENTS

By Gary Marneweck and Mandy Uys

While environmental water allocation has classically focussed on rivers (and wetlands directly associated with rivers), the need to adapt the relevant approaches to the broader suite of wetlands has been addressed in some countries since the late 1990s. In SA, the wetland Reserve Determination process was drafted in 1999, and has been used in a number of wetland systems. The method is due for review and further development later this year (2004). The aim of this chapter is to provide a background to the current Reserve Determination process, its shortcomings, and recommendations for its further development. Although this is not strictly part of the Terms of Reference of this study, the subject has been addressed to provide an understanding of the role of bioassessment within a revised wetland Reserve process.

A key issue in the current method is the reliance on a Habitat Integrity Assessment method for determination of Present Ecological State Category (PESC), Ecological Importance and Sensitivity Category (EISC), and Ecological Category (EC, previously Ecological Management Class). This is considered an inadequate basis for the determination of these key parameters. Two recommendations are made. Firstly, the inclusion of a new South African hydrogeomorphic (HGM, functional) assessment protocol, WETLAND-ASSESS, as a means of determining wetland functionality and assessing likely changes in function as the result of altered hydrology. Secondly the incorporation of one or more indices of biological integrity (IBIs) to evaluate aspects of wetland ecological character, and to provide information for use in determining the relevant biotic water requirements. WETLAND-ASSESS includes an HGM classification system recommended for use in the Reserve process. It is designed for palustrine wetlands only, but has already been used in Reserve Determinations by Marneweck and colleagues. These specialists recommend alternative procedures for the determination of PESC, EISC and EC in lacustrine wetlands and pans.

In Australia, the field of environmental water allocation (EWA) for wetlands is somewhat ahead of South Africa, to the extent that programmes exist for the monitoring of ecosystem response to EWA delivery. Two key reports regarding EWA are referred to: one a framework for assessing the success of EWAs in maintaining important wetland systems; and the other a guide to the means of estimating water requirements of plants in Australian floodplain wetlands. Similar approaches are followed in both. These are valuable in providing a perspective on the type of information required in setting (and evaluating) the Ecological Reserve for rivers; and stimulate thought as to how this information could be collected alongside that required for bioassessment. For example, the rivers Reserve Determination process considers the response of the biota to adjusted hydrological regime. Standard methods are in development for this purpose. This enables the fieldworker, who is undertaking the bioassessment, to collect additional information on their biotic variable, which will be used in determination of biotic response to different flow scenarios.

8. RECOMMENDATIONS

A number of recommendations are presented for the second phase of this project: the development of an integrated assessment protocol for use in evaluating wetland condition. These recommendations are based on the consultative and review processes of this project, but should not be considered prescriptive and final outputs of Phase 1. It is recommended that these suggestions be discussed by the Project Team, in consultation with members of the Steering Committee and with other key wetland specialists. The recommended format for this meeting is a specialist workshop. The recommendations are made bearing in mind the requirements of an integrated assessment protocol, and the existing constraints that the development of such a protocol would entail.

1	To collaboratively develop a national framework for a Wetland Inventory, Assessment and Monitoring System (WIAMS) to form the basis of a Wetland Monitoring Programme for SA. This programme should be coordinated by DEAT (who also have responsibility for the Wetlands Inventory), but should have the custodianship of a number of different organisations, projects, government bodies, and programmes.
2	To adopt an approach of combining functional and biological assessment methods in the evaluation of wetland state. To measure environmental variables alongside these as a standard procedure.
3	Prioritise the development of indices of biological condition (IBIs) or similar methods as follows: i. Plants ii. Aquatic macroinvertebrates iii. Fish iv. Algae and Diatoms
4	Utilise the extensive existing knowledge and experience-base, and methods already in use, for the further development of a plant-based index of wetland condition for incorporation into the Wetland Reserve Determination method.
5	Develop an invertebrate index for use in wetland assessment, based either on the IBI approach used in the US, or the sensitivity index approach used in Australia. Initially, use metrics which have been tested elsewhere and shown correlation with human disturbance and water quality variables.
6	Develop a fish Index of Biological Integrity (along similar lines to that used in rivers in South Afric) for use in wetlands with direct connectivity to river systems, i.e. the following palustrine wetland types: floodplain; valley bottom with a channel, valley bottom without a channel. DWAF has the capacity to drive this development.
7	Incorporate algae into the wetland assessment process, at a purely descriptive and field-based level. Commission a colour photographic guide to the algae of aquatic ecosystems in SA for this purpose.
8	Assist and encourage the development of quantitative and computer-assisted methods for the use diatoms in wetland assessment. The development of an index using algae and diatoms should be seen as a longer-term goal.

9	Encourage more directed research into birds and amphibians of wetlands. Amphibians have potential as qualitative indicators of the larger spatial-scale issues relating to wetlands within landscapes, and wetland connectivity within and across continents. Investigate linkages with specialists who have experience in the use of amphibians as bioindicators, or who see potential for the use of audio recordings (frog calls), to provide a wetland biodiversity and condition assessment.

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1 INTRODUCTION

1.1 BACKGROUND

Since the late 1960s, it has been recognised globally that wetlands not only benefit people by supporting a host of ecological and hydrological functions (e.g. water supply, water purification, flood control), but that they are also critical for the conservation of biological diversity (e.g. Ramsar COP7, 1999). The wise use, conservation and management of these systems have been increasingly under the international spotlight since the international *Convention on Wetlands of International Importance especially as Waterfowl Habitat* held in Ramsar, Iran, in 1971 (commonly referred to as the 'Ramsar Convention').

The Convention came into force in 1975, and by late 2003 had 138 Contracting Parties, of which South Africa was the fifth (Ramsar Information Paper 2). Although the primary focus of the first Convention was the protection of water-fowl habitat, subsequent annual 'Conferences of Parties' (COPs) have looked at broad-ranging issues covering all aspects of wetland conservation and wise use. As a signatory to the convention, South Africa is obliged to show its commitment to the requirements of both the Convention and the various COP reports, through three sets of actions:

- working towards the wise use of their wetlands through a wide range of actions and processes contributing to human wellbeing, including water allocation, river basin management, and undertaking inventory and assessment;
- devoting particular attention to the further identification, designation and management of a suite of sites for the List of Wetlands of International Importance (the Ramsar List), and ensuring the effective monitoring and management of those sites; and
- cooperating internationally in their delivery of wetland conservation and wise use, through the management of transboundary water resources and wetlands and shared wetland species (Ramsar Information Paper 3).

The estimated loss of global wetland cited by the Ramsar Convention on Wetlands is 50% (Dini 2004). It is estimated that about 50% of wetlands in the United States and up to 70% of wetlands in Western Australia have been lost through wetland conversion of one or another kind (Halse 1989 cited by Chessman 2002; Euliss *et al* 2001). Although no systematic national survey of wetland loss has been undertaken in South Africa, studies in several major catchments have revealed that between 35% and 50% of the wetlands, and the benefits they provide, have already been lost or severely degraded (Dini 2004).

It is possible that up to half of the wetland surface in South Africa has been lost or severely degraded as a result of unsustainable social and economic pressures (including water abstraction, drainage, mining [including peat mining], overgrazing, cultivation, sewage waste disposal, or infilling wetlands for land reclamation purposes). This has raised the concerns of both the Department of Water Affairs and Forestry through the National Water Act (NWA, Act No. 36 of 1988), and Environmental Affairs and Tourism through its National Environmental Management Act (NEMA, Act No.107 of 1998).

The NWA (Act No.36 of 1998) allows for sustainable development, while ensuring the conservation and protection of biodiversity in water resources. The Act requires that the Minister of Water Affairs and Forestry use a classification system[1] to determine the class and resource quality objectives of water resources considered to be significant. Once the class of the resource has been determined, the Minister is required to determine the Reserve[2] for that resource. This is achieved via a stepwise method in which the Reference (pre-impact) condition, Present

1 This is currently in final development by DWAF.

2 The Reserve comprises a basic human needs reserve (BHNR) and an ecological reserve (ER). The BHNR provides for the basic needs of humans served by the water resource in question (including drinking, hygiene, and food preparation). The ER relates to the water required to protect the aquatic ecosystems of the water resource.

Ecological State, Ecological Importance and Sensitivity are determined by specialists, and used to define a recommended Ecological Category (EC, previously Ecological Management Class) for the resource. The EC serves as the basis for the quantification of a number of scenarios relating to the Ecological Water Requirements of the system. The Reserve Determination process ends with a ministerial decision regarding the appropriate Management Class for the resource, and the specification of the Reserve.

Resource quality objectives (RQOs) are incorporated in the Reserve, and relate to a number of characteristics of the water resource in question, including the Reserve itself, the characteristics and quality of the water resource and the instream and riparian habitat; the characteristics and distribution of aquatic biota; and the regulation or prohibition of instream or land-based activities which may affect the quantity in or the quality of the water resource.

DWAF's commitment to follow Integrated Environmental Management (IEM) and Integrated Water Resource Management (IWRM) procedures in their resource planning and management had led to the development of a suite of tools to assess the environmental flow requirements of aquatic ecosystems. These included Instream Flow Requirement (IFR) methods, which were initially used for rivers and estuaries (Taljaard et al. in prep).

The process of refining and adjusting these available methods to meet the requirements of the NWA began in 1999, with the development of both generic and ecosystem-specific Reserve Determination methods (DWAF 1999). To meet with the requirements of catchment management, or more specifically, Integrated Water Resource Management, it was necessary to recognise - and formulate approaches for the management of - the separate but linked aquatic ecosystems within a catchment – wetlands, rivers, groundwater, and estuaries (e.g. DWAF 2004).

DWAF's preliminary method for Reserve determination in wetlands (DWAF1999) has been used in a number of Reserve determinations to date (Marneweck pers.comm. 2004, see Section 7.2). A revision and reworking of this method by DWAF is due in mid-2004 (Weston, pers.comm., March 2004). For this process and its outcome to be successful, a number of existing concerns must be addressed, including that of developing an integrated method to assess the ecological integrity and overall condition of wetlands. **This requirement is the purpose of this project.** The only form of wetland condition assessment included in the preliminary 1999 method is a Habitat Assessment Index, adapted from the Integrated Habitat Assessment System (IHAS) of Kleynhans (1999). This was devised for use in rivers, alongside a number of bioassessment methods. This system has not yet been thoroughly tested, and in the absence of integrated biotic indices, does not provide a comprehensive means of assessing wetland ecological character.

In the further development of DWAF's Wetland Reserve Determination (WRDM) method, and in order to meet with DWAF's IWRM approach and South Africa's international obligations to the Ramsar Convention, it has become necessary to develop a scientifically-valid, integrated form of assessment which will facilitate evaluation of different types of wetland ecosystems for a suite of purposes, including:

- determination of (or assisting with determination of) the reference condition, present ecological state, ecological and social importance and sensitivity, future desired state;
- determination of the Recommended Ecological Category;
- development of Resource Quality Objectives (WRDM);
- the assessment and monitoring of key wetlands, to meet with SA's Ramsar obligations.

These needs provide the rationale for the current project. Within DWAF, the Directorate: Resource Quality Services has a responsibility to develop or contribute to and guide the development of such a method.

1.2 PROJECT OUTLINE AND TERMS OF REFERENCE

The purpose of the project is to develop an integrated biological assessment method that will be used as one of a set of tools to evaluate the overall integrity (health or condition) of wetlands, based on a number of different criteria.

Due to complexity of wetland systems and the general paucity of knowledge on their structure and function or dynamics, the project was designed in phases, to ensure that the necessary expertise and adequate funding were obtained for each phase in order to develop the method successfully. The project comprises the following three phases:

Phase I	Situation Analysis	This is the subject of this report.
Phase II	Development of the integrity index	This will be based on the findings of Phase I.
Phase III	Testing, refinement, implementation and evaluation of the assessment method	This will involve the trialling and refinement of the method developed during Phase II.

The Terms of Reference for Phase I of the project was amended slightly during the course of the study. In its final form, the TOR is:

- to review the approaches and methods used worldwide in wetland bio-assessment;
- on the basis of this review, to make recommendations regarding the development (Phase II) of an integrated bioassessment technique for different types of South African wetlands. Amongst other uses, this protocol will be applied in the Wetland Reserve Determination process, and possibly incorporated into the River Health Programme.

The Steering Committee for this project includes representatives of the DWAF Directorates of Information Management, Resource Quality Services, Resource Directed Measures, Water Abstraction and In-stream Use (formerly Social and Ecological Services), the Water Research Commission (WRC), the Department of Environmental Affairs and Tourism (DEAT), and Working for Wetlands (WfWet).

1.3 REPORT FORMAT

This report is presented in eight chapters.

Chapter 2	Provides the reader with the context for the remainder of the report. Different approaches within the field of wetland assessment are discussed. Concepts and terms are defined.
Chapter 3	An introduction to the different methodological approaches to wetland assessment.
Chapter 4	A description of those South African agencies, organisations, projects and programmes currently contributing to wetland wise use, conservation and management.
Chapter 5	A situation analysis of wetland assessment approaches and protocols internationally.
Chapter 6	A study of the different biological variables used in wetland assessment, and the types of methods developed for these.

Chapter 7	An introduction and background to the issue of wetland water requirements, and environmental water in wetlands.
Chapter 8	Recommendations are made for Phase 2 of this project (index development), on the basis of the findings of the project process.

2 APPROACHES, CONCEPTS AND DEFINITIONS

2.1 INTRODUCTION

Many problems can arise out of poor or loose use of terminology, with generalisation causing more rather than less confusion (e.g. Butcher 2003). It is recognised that different definitions of existing terminology are likely to exist in the field of wetland management, science and research. Specifically, the definitions used for the terms 'assessment' and 'monitoring', vary between the Ramsar organisation, the US Environmental Protection Agency (US EPA), the various Australian agencies, the Department of Water Affairs and Forestry (DWAF), and other organisations. It is important that this is recognised and addressed at the outset.

Alignment with DWAF terminology is sought wherever possible and appropriate, particulary with that proposed in the DWAF framework for national monitoring programmes for water resource monitoring (DWAF 2004). However, consensus on terminology, which this monitoring framework aims for, is not always possible when discussing the methods and approaches adopted by other countries or organisations. Many of the DWAF (2004) definitions are generic to aquatic ecosystems, and more specialised definitions may be required when focussing on wetland systems. This section is provided in order to map the use of terminology in this report onto that of DWAF (2004).

2.2 WETLANDS

A wetland is defined in the National Water Act (No. 36 of 1998) as '*land which is transitional between terrestrial and aquatic systems, where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil'.*

This is the definition originally developed by Cowardin (1979) for the wetland classification system, and applies for the purposes of this report. By this definition, in order for an area to be classified as a wetland, it must meet at least one of the following criteria:

- *at least periodically, the land supports predominantly hydrophytes;*
- *the substrate is predominantly undrained hydric soil;*
- *the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season.*

The NWA definition differs substantially from the Ramsar (1971) definition (Articles 1.1 and 2.1): '*For the purpose of this Convention, wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres*.'

The DWAF definition clearly excludes rivers and estuaries. However, the wetland classification system used in the inventorising of wetlands in South Africa, and included in the preliminary Reserve Determination Method (DWAF 1999, Appendix W1), ensures compatibility with the Ramsar definition by incorporating in the definition of wetlands what Cowardin et al. (1979) termed 'deepwater habitats', which are defined as:

'permanently flooded lands lying below the deepwater boundary of wetlands. They include environments where surface water is permanent and often deep, so that water, rather than air, is the principal medium within which the dominant organisms live, whether or not they are attached to the substrate'.

The preliminary wetland Reserve Determination method (DWAF 1999) caters for following classes of South African wetlands, based on the Dini, Cowan & Goodman (1998) classification system:

- Lacustrine: Limnetic and Littoral (natural freshwater lakes);
- Palustrine: Flat, Slope, Valley Bottom, Floodplain (freshwater marshes, peatlands, springs, swamp forest, floodplains); and
- Endorheic (permanent and seasonal pans).

'Palustrine' wetlands includes wetlands associated with rivers, but not contained within a channel.

A functional classification for SA wetlands has subsequently been proposed for incorporation into the Reserve process, and is discussed in the following section.

2.3 WETLAND CLASSIFICATION

Note: The difference between classifying wetlands on the basis of morphological or hydrogeomorphic characteristics (as described below), and the DWAF and NDA 'Classification System', which is a grading system which uses various condition categories to describe the condition of a water resource or part thereof.

The idea of classifying wetland systems is to group similar *types* of wetlands (i.e. with homogenous natural attributes) into categories and subcategories, typically for the purposes of wetland inventory. Each wetland type in a classification system represents a broad set of natural hydrological, geomorphological and ecological characteristics. The aim of classification is to aid identification and understanding of the main wetland types occurring in an area or at a site, and provide a broad-level characterisation of the system. The famous Cowardin wetland classification system (Cowardin et al. 1979) was successfully used by the US National Wetland Inventory for almost 20 years (Dini et al. 1998).

In South Africa, the classification system of Dini, Cowan and Goodman (1998), which is based on the Cowardin system, recognises six broad types of wetland systems: marine, estuarine, riverine, lacustrine, palustrine and endorheic. This classification was used as the early basis of mapping and inventorising wetlands in South Africa, and is the system included in the current Wetland Reserve Determination Process (DWAF 1999). Here, 'riverine' wetlands are defined as those contained within a channel (i.e. rivers, rather than wetlands associated with rivers), and are excluded from the wetland Reserve Determination method.

The hydrogeomorphic classification (HGM) system developed for the US Army Corps of Engineers by Brinson (1993) is now the system most commonly applied in the US. This is based on the concept that while each wetland may be unique, each can be placed into categories in which similar wetlands share similar *functional properties.* The focus is on hydrological and geomorphic controls which maintain many of the functional aspects of wetland systems. By emphasizing the abiotic features of wetlands, HGM was kept relatively independent of the biogeographic distribution of biota (Brinson 1993). The HGM method was adapted for South African conditions by Marneweck and Batchelor (2002) and more recently again by Kotze, Marneweck, Batchelor, Lindley and Collins (2004). The second adaptation is a simple system designed for use in wetland assessment and inventory, and is appropriate for application in the wetland Reserve Determination method. Seven wetland types are recognised. The system focuses on the hydrogeomorphic determinants of wetlands and incorporates geomorphology, water movement into, through and out of the wetland, and landscape/topographic setting. It is described in Section 7.3.

2.4 WETLAND INVENTORY, ASSESSMENT AND MONITORING

Recent literature on the subject of wetland assessment from Australia indicates that there may be value in considering separating the terms ‘inventory’, ‘assessment’ and ‘monitoring’ when designing data-gathering exercises in wetlands (Finlayson et al. 2001, Butcher 2003). This may merit further attention, since these three exercises require different types of information and collection activities.

While the separation of the terms for the purposes of this report could potentially conflict with DWAF (2004) definitions (as described below), the term ‘assessment’ is widely accepted around the world in the field of wetland evaluation, and in Ramsar documentation, and for this reason it is felt that it should be included here, with adequate definition. The DWAF Strategic Framework for National Water Resource Quality Monitoring Programmes (DWAF 2004) does recognise the inevitability of this sort of conflict in terminology:
’This document does not set out to propose a terminology that everyone involved in water resource quality management in SA is expected to use henceforth. Rather, as a first step in starting an extensive process of consensus building amongst all of the role players, it sets out to very clearly explain how terminology is used so that users can map their own current use of terminology onto it’.
Thus, the use of the terminology is clearly described and mapped onto the DWAF Framework, and the rationale for the slight non-alignment is provided.

2.4.1 Wetland inventory

Wetland inventory is defined as the collection and/or collation of core information for wetland management, including the provision of an information base for specific assessment and monitoring activities (Finlayson et al. 2001). Wetland delineation and mapping activities fall under this definition.

The objective of the SA wetland delineation procedure is to identify the outer extent of the ‘temporary’ (outermost) zone of the wetland, which marks the boundary between the wetland and the terrestrial areas. The process makes use of four specific indicators:

- the Terrain Unit Indicator which helps identify those parts of the landscapes where wetlands are likely to occur;
- the Soil Form Indicator which identifies the soil forms, which are associated with prolonged and frequent saturation;
- the Soil Wetness Indicator which identifies the morphological ‘signatures’ (mottles etc.) developed in the soil profile as a result of prolonged and frequent saturation;
  the Vegetation Indicator, which identifies the hydrophilic vegetation associated with frequently saturated soils (DWAF 2003).

2.4.2 Wetland assessment

The term 'wetland assessment' can describe a suite of actions relating to the evaluation of wetland health, the making of permit or license decisions, the targeting of wetland rehabilitation activities, undertaking catchment management, developing wetland classifications, protecting water supplies and the environment, and many more.

DWAF, in their 'Strategic Framework for National Water Resource Quality Monitoring Programmes' (Draft 1-15, 2004) do not explicitly define the term, but maintain that 'assessment' of water quality is used in two ways: to mean the value-addition activities of monitoring programmes (i.e. the conversion of data to information), to mean the activities of he users of information adding their experience and knowledge of the subject area to the information received, in order to make a decision.

The authors comment that problem with these definitions is that the first interpretation of the term is already intrinsic in the definition of 'monitoring', and that the second interpretation is external to 'monitoring'. The authors suggest that the term 'monitoring and assessment' should not be used, as it creates confusion between the role of the monitoring programme and the users of the information generated by it. The term 'monitoring' is thus used on its own in the framework, and *includes* the kind of assessment required to generate standard information products from data. The definition applies to all water resources, and is not specific to wetlands.

The US EPA refers to the goal of assessment being the evaluation of the condition of a wetland relative to a known range of condition from wetlands across a disturbance gradient (US EPA 2002). It involves an evaluation of how a specific wetland or range of wetlands *functions*, and increasingly includes an evaluation of the condition or ecological integrity of the wetland system (US EPA 2002).

Recent Australian literature differentiates between monitoring and assessment, in an attempt to simplify and standardise wetland terminology internationally, specifically for the purposes of Ramsar (Butcher 2003, Finlayson et al. 2001). As SA is a signatory to Ramsar it is felt that it may be important to consider this approach, providing it is not seen to conflict with the DWAF monitoring strategy (DWAF 2004).

The definition of 'assessment' from the Australian literature is as follows: *'Assessment is the identification of the status of, and threats to, wetlands as a basis for the collection of more specific information through monitoring activities'* (Finlayson et al. 2001). In this definition, the assessment of the wetland would follow a certain set of protocols, would generate data, and would result in a series of outputs which would provide information regarding present state and reference condition. These outputs would provide the basis for the design of a purpose-driven wetland monitoring programme. The use of the term 'assessment' in this manner may be a consideration for the South African wetland lexicon, as described in Section 2.4.4, 'The relationship between inventory, assessment and monitoring'.

2.4.3 Wetland monitoring

According to the most recent draft of the DWAF 'Strategic Framework for National Water Resource Quality Monitoring Programmes' (DWAF 2004), the purpose of monitoring is to deliver to water resource managers, planners and other stakeholders the management information required about water resource quality. In terms of the DWAF (2004) definition, an activity qualifies as 'monitoring' if it includes three core, interconnected functions: data acquisition, data management and storage, and information generation and storage.

The authors refer to the confusion arising from the different ways in which the term 'assessment' is commonly used: either to mean the conversion of monitoring data to information (interpretation, comparison, calculation of trends, etc.) or to mean the addition of knowledge and experience to information they have received, in order to make a decision or execute an action (DWAF 2004). The DWAF framework thus uses only the term ‘monitoring’, with the assumption that this term includes the kind of assessment required to ‘generate standard information products from data’ (DWAF 2004). The term ‘assessment’ is omitted from the text.

The US EPA (2002) does not distinguish clearly between the terms ‘monitoring’ and ‘assessment’. From a review of EPA literature, it is assumed that ‘monitoring’ implies the actual *act* of measuring involved in the initial assessment of wetland condition, and the follow-up long-term measuring of indicators of condition. The following mixed use of terms is commonplace: ‘*The most direct and effective way of evaluating the biological condition of wetlands is to **directly monitor** the biological component of wetlands through the use of **bioassessments**, and to support that information with chemical and physical data. Relying on surrogate measurements or using **monitoring tools** designed for other purposes (e.g. rapid functional **assessments**) may provide incomplete and misleading results. Bioassessments can help prioritise where to follow up with additional monitoring, help diagnose the causes of degradation, and provide data to make informed management decisions about protecting and restoring wetlands*’.

Recent Australian wetland literature describes *monitoring* as an evaluation of how, and to what extent, the ecological character of a wetland has changed. It is dependent on having baseline inventory and assessment data (Butcher 2003). If we choose this approach, the definition of ‘monitoring’ for the purpose of this report is as follows: ‘*wetland monitoring is the collection of specific information for management purposes in response to hypotheses derived from assessment activities, and the use of these monitoring results for implementing management*’ (Finlayson et al. 2002). Except for it’s reliance on the output of ‘assessment’ activities, this is close to DWAF’s (2004) definition of the purpose of monitoring.

2.4.4 The relationship between inventory, assessment and monitoring

The spatial scale of the analysis determines the objective/s of inventory, assessment and monitoring. The three are considered separate but strongly linked, by Finlayson et al. (2002) and Butcher (2003). All three exercises require differing types of information, and support each other in various ways, as indicated by the relationship graphic (Figure 2.1).

Wetland **inventory** collects the information to describe the ecological character of wetlands, and provides the basis for guiding the development of appropriate assessment and monitoring. **Assessment** identifies the threats and values of wetlands, and changes to ecological character, and on the basis of this, provides the information from which hyphotheses are derived for monitoring activities. **Monitoring** provides information on the extent of change from a natural or reference condition (Finlayson et al. 2002).

Finlayson et al. (2002) argue that, as all three are important data-gathering exercises, any ‘wetland assessment system‘ (WAS) should comprise components of each, with the extent of each component being determined by individual management needs and the extent of existing information. These authors propose the use of the term ‘Wetland Inventory, Assessment and Monitoring System’ (WIAMS) to describe a composite framework. This is elaborated on further in the final chapter of this report (Chapter 8).

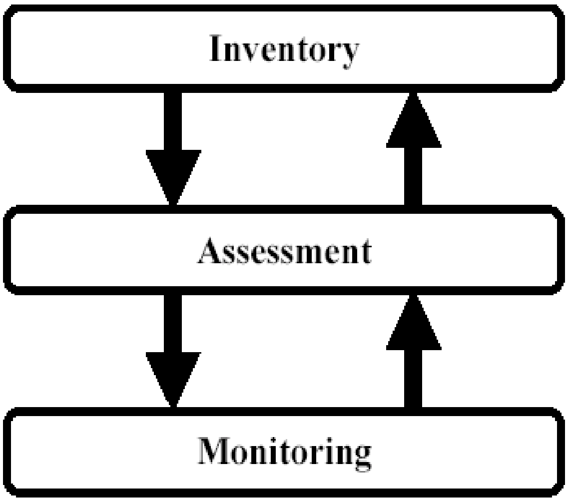


Figure 2.1 The link between the concepts of wetland inventory, assessment and monitoring (from Finlayson et al. 2001). and proposed for acceptance within the technical guidelines adopted by the Ramsar Wetlands Convention.

2.5 WETLAND DELINEATION

Delineation is a process used in the identification of the outer edge of a wetland, which marks the boundary between the wetland and adjacent terrestrial areas (DWAF 2003). It is thus the first step in classifying an area as a 'wetland'. The approach to delineating the wetland boundary is to identify a suite of indirect indicators of prolonged saturation of soils by water. These include wetland plants (hydrophytes) and wetland (hydromorphic) soils. The approach advocated in South Africa for delineation was identification of the outer edge of the *temporary zone* of the wetland (the outermost zone, which is saturated for only a short period of the year, but for sufficient time for the formation of hydromorphic soils and the growth of wetland plants) (DWAF 2003).

2.6 ECOLOGICAL CHARACTER

The **ecological character** of a wetland is defined as: *'the structure and inter-relationships between the biological, chemical, and physical components of the wetland. These derive from the interactions of individual processes, functions, attributes and values of the ecosystem(s)'* (Ramsar).

2.7 REFERENCE CONDITION / REFERENCE WETLANDS

‘Reference condition’ describes the characteristics of a wetland least impacted by anthropogenic activities. It can be based on data from sites that represent the least-impacted condition for a particular wetland type within a landscape, ecoregion, catchment or area (e.g. Butcher 2003). ‘Reference wetlands’ are those wetlands displaying reference conditions.

3 BROAD APPROACHES TO THE ASSESSMENT OF WETLAND CONDITION

3.1 INTRODUCTION

There are a number of different approaches to the assessment of wetland condition, designed for a suite of different applications. These are briefly introduced here to provide clarity and context for the rest of this report.

3.2 TYPES OF ASSESSMENT

The US EPA recognises two broad approaches to wetland assessment: functional assessment and biological assessment (US EPA 1998f). The purpose of each is defined as follows:

'The purpose of ***functional assessments*** *is to evaluate current wetland functions and predict potential changes to a wetland's functions that may result from proposed activities. A wetland is compared to similar wetlands that are relatively unmodified (reference wetlands). The approach to development of a functional index is based on combining variables that are typically structural /physical measures, or indicators that are associated with one or more ecosystem functions. The three major categories into which functions are assigned are: hydrological (e.g. water storage), biogeochemical (e.g. removal of elements), and physical habitat'* (Brinson in US EPA 1998f).

'*The purpose of* ***bioassessment*** *is to evaluate a wetland's ability to support and maintain a balanced, adaptive community of organisms having a species composition, diversity and functional organisation comparable with that of minimally disturbed wetlands within a region. The condition of the biota will indicate if the wetland is degraded by any chemical, physical, or biological stressors, and will help scientists diagnose the stressor/s causing the damage. Biological assessments (bioassessments) also detect intermittent stressors or the cumulative effect of multiples stressors' (*US EPA 1998f).

Between forty and fifty methods to assess wetland function are available in the US (Bartoldus 1999). These range in their level of rigor from those based on professional opinion to sophisticated peer-review mechanistic models. They thus differ in their level of detail, objectivity and repeatability of results (Thiesing 2001). While each method may be useful for one or more applications, there is still no single standardised method which can be applied to every situation.

Although functional assessment methods include a function for support of wildlife habitat, they usually do not measure directly the biological communities in wetlands, and cannot substitute for a biological assessment method. The argument is that biota need to be measured in order to assess human and other impacts, and as a basis for setting objectives and targets for management, protection or rehabilitation of wetlands.

The four different types of methods generally to assess wetland function or biota are shown in Table 1.

Table 3.1. Four broad categories of methods used to assess wetlands, and their use in functional or biological assessment. *Adapted from Thiesing 2001.*

Method Type	**Description**	**Applicability**
Inventory & classification	Objective techniques which describe the areal extent and/or types of wetlands within a given landscape.	Functional
Rapid Assessment Protocols	Low-cost techniques in which data used to assess the system is gathered at a relatively low level of confidence, in a short period of time. Results tend to be qualitative or may involve subjective information (e.g. professional judgement).	Functional, Biological
Data-driven Assessment Methods	These are usually model-based and expensive to develop. They provide a high level of repeatability. Results often have a predictive value.	Functional, Biological
Bioindicators / Indices of Biotic Integrity (IBIs)	These involve a selected set of variables which are measured across wetland types. Each variable may be evaluated separately, or used to develop a multimetric index which can be used to measure the ecological integrity of the system, and can also be used as triggers to identify long-term changes. These methods are not considered to provide a reliable assessment of wetland functional capacity.	Biological

3.3 BIOASSESSMENT

The fauna and flora of a wetland may be used in system assessment in one of two ways: either to reflect the functional integrity of the system, or to reflect the biological integrity of the system. Until the late 1990s, functional assessments were the most common form of assessment used for wetlands in the US. More recently, the importance of biological assessment in has been recognised, and means of using the two techniques in support of each other are being actively investigated in the USA (US EPA 1998f).

Bioassessment involves the use of living organisms to assess the biological integrity of a habitat, and the effects of human actions on the system. Biological integrity is defined as '*the ability of an aquatic ecosystem to support and maintain a balanced, adaptive community of organisms having a species composition, diversity and functional organisation comparable to that of natural habitats within a region*' (Karr and Dudley 1981). This form of assessment has commonly been used in resource management, for applications such as determining the use designation for a water resource, water quality standards, or environmental water requirements (Bartoldus 1999).

Bioassessments are used for a wide range of purposes: to provide an early-warning of wetland condition; to diagnose the type of stressor damaging the biota (through the use of metrics which correlate with particular types of disturbance); to assist in management, maintenance and restoration of wetland condition; to evaluate the effectiveness of protection and restoration activities; to develop and support water quality standards; to certify that permits maintain water quality; to track water quality condition within wetlands (e.g. US EPA 1998b); and to monitor the outcomes of environmental flow allocations (Davis et al. 2001).

The modular series, '*Methods for Evaluation of Wetlands*', produced in 2002 by the US EPA, provides guidelines for the development of indices using invertebrates (US EPA 2002a), plants (US EPA 2002b), algae (US EPA 2002c), amphibians (US EPA 2002d), and birds (US EPA 2002e) in evaluation of wetland condition. The methods for fish are still in development (US EPA website, 30.04.2004).

Three broad steps are followed in bioassessment:

1. **Collection of supporting information:** Background information is collected and potential threats to the waterbody condition are identified. The wetland is classified into a type (or types). Location of the wetland is documented. Present or historic drainage of wetland is investigated. Present and historic landuses are identified.

2. **Standard tests and measurements:** Direct measurements of biological attributes of the waterbody (metrics), together with standard chemical and physical measurements of the wetland and surrounding landscape.

3. **Comparison to reference conditions:** The ecological condition of the wetland is compared with minimally impacted reference sites of the same type and ecoregion. (US EPA 1998a).

3.3.1 The Index of Biological Integrity (IBI)

The IBI concept has been widely used in bio-assessment worldwide, and in some parts of the world (US in particular) has become almost a standard format for the assessment of biota within a water resource. An IBI is a multimetric index (cumulative sum of component metric scores) which presents a picture of the ability of a resource's habitat/s to support and maintain a balanced, integrated, adaptive biological system having the full range of elements expected in a region's natural habitat. Each IBI thus comprises several metrics, each of which has been shown to have a significant response to the effects of development and human activity.

These protocols are designed for first-level ('red flag') assessments, to screen a large number of sites rapidly. They provide information for more detailed follow-up studies to identify the stressors to the biota, where necessary, at individual sites. The IBI of Karr and Chu (1997) was developed for the assessment of a range of aquatic habitats, including wetlands. Bartoldus (1999) reported that the IBIs for wetlands were in development by several states in the US, but had not yet been applied in a regulatory context.

For the effective and direct assessment of wetland *condition*, the approach recommended by the US EPA is:

i) to directly measure the condition of a wetland's biological community, using a bioassessment method such as an Index of Biotic Integrity (IBI);
ii) to observe and measure the chemical and physical characteristics of a wetland and its surrounding landscape.

The EPA recommends that more than one IBI be developed for different applications, such as in the case of a Montana Department of Environmental Quality, which uses macroinvertebrate metrics to illustrate sensitivities to physical changes to wetlands, and algal metrics to show sensitivity to nutrient enrichment (EPA 1998a).

A generic IBI procedure
(*Sourced from Bartoldus 1999)*

Homogenous sets of environments (wetland classes/types and subclasses/subtypes) are identified within or across ecoregions. The 'set' to be studied is selected. A number of metrics (measurable attributes empirically shown to change in value along a disturbance gradient) are selected for the system. These represent the ecological indicators (diagnostic metrics through which biological integrity can be assessed). These must have been shown to give statistically reliable and relevant signals about the effects of human interference (e.g. it must be shown that the metric 'invertebrate taxa richness' shows a significant relationship to increase in human influence). Sampling protocols and designs are developed to ensure accurate measurement of these metrics. Data are collected from each site, and analysed to determine the reference standard for each metric. The range of metric values are changed to converted metric scores. These are scores assigned to quantitative ranges for each metric. There are three: 1 (severely degraded), 3 (moderately degraded), or 5 (at or close to natural). An IBI is then calculated for the site.

Text Box 3.1. Types of metrics typically included in an IBI

Taxa richness and composition
Total no. of taxa
No. of particular taxa (e.g. Ephemeroptera, Odonata, Trichoptera)
No. of long-lived taxa
Ratio of particular taxa (e.g. Ephemeroptera: Odonata: Trichoptera)
Tolerance
No. of intolerant taxa
Percent of individuals in intolerant taxa
Feeding ecology
Percent of predator individuals
Population dominance
Percent dominance

3.4 FUNCTIONAL ASSESSMENT

Functional assessments were developed principally for evaluating the potential impacts of developments which threaten wetland ecosystems (see Section 5.3.2), and are used to assess the success of wetland rehabilitation projects, by evaluating the change in wetland functioning over time (US EPA 1998f). These protocols are usually designed to estimate the change in functioning resulting from the alteration of a wetland (either positive or negative). they use minimally-impacted wetlands (within each wetland class) as a reference or benchmark. Each function is scored relative to that of a reference wetlands in the same locality and class/type and subclass/subtype. The index value of each variable is accompanied by descriptions of estimates and measurements.

Simplistically, the key steps in developing a functional assessment method are as follows (from US EPA 1998f):

1. Classify the wetland by geomorphic setting for the purpose of partitioning natural variation (thus allowing variation by impacts to be more easily detected within a regional subclass).

2. In consultation with a multidisciplinary group of experienced professionals (hydrology, geomorphology, soil science, vegetation, ecology, etc), develop a profile for the wetland subclass that characterises it according to its geology, hydrology, biogeochemistry, plant and animal communities, and typical alterations that may have happened historically.

3. Identify reference standard wetlands from a subset of reference sites that are minimally degraded or natural. Characterise these sites by estimating or measuring indicators and field variables that will be used to develop models which relate the measurements to functions.

4. Develop scales for the variables that distinguish the reference standard wetlands from the degraded ones.

5. Combine variables into a functional assessment model. Test and validate.

Properly constructed models of functions for a particular wetland subtype will quantify the similarities and differences between a wetland site being sampled and reference standard wetlands. The model should also predict the changes that will result from proposed alterations to the site.

3.5 HABITAT ASSESSMENT

Within an ecosystem evaluation framework, habitat assessment is often used alongside bioassessment, to provide information on the quality, quantity and suitability of the physical environment supporting the biota being measured (e.g. River Health Programme). The use of these two approaches in tandem provides an effective means of interpreting biotic data which may otherwise be misleading.

In the early 1980s, the US Fish and Wildlife Service developed a habitat evaluation procedure (HEP) for wetlands. This documents the quality and quantity of available habitat for various wetland biota, and is still in use at present. A simpler version of this method, called the Habitat

Assessment Technique (HAT) has since been developed in the US (Graber & Graber 1976). These are indirect measures of wetland condition and were designed for use in wildlife habitat assessments, trade off analyses and compensation analyses (HEP), or evaluate different land areas for acquisition (HAT; Bartoldus 1999). The single assessment protocol included in the current Wetland Reserve Determination process is that for wetland assessment, the Habitat Integrity Assessment (*as modified from Kleynhans 1999).*

4 SOUTH AFRICAN WETLAND PROGRAMMES AND PROJECTS

4.1 INTRODUCTION

The purpose of this chapter is to provide a background and a 'roadmap' to the wide range of organisations involved in research, management, conservation and rehabilitation activities relating to wetlands in South Africa, and the projects that they are undertaking which have relevance to the current study. This should provide the context within which to interpret this report, and within which to set the future phases of this DWAF project. The development of an integrated assessment method for wetlands could and should have a direct bearing on a number of activities currently underway in the field, and could equally benefit from interaction with these.

4.2 WORKING FOR WETLANDS

The following information is sourced from the Working for Wetlands Annual Report 2003/4, Dini (2004), and Dini (pers.comm. 2004).

Working for Wetlands (WfWetlands) is a national programme which is nested within the Environment and Culture sector of the Expanded Public Works Programme. The focus of WfWetlands is on maximising the contribution of wetlands to biodiversity conservation and human wellbeing, through the development and management of projects which focus on the conservation, rehabilitation and wise use of wetlands. Projects are aligned with national policies, international agreements and conventions. The projects are designed to maximise employment creation, the creation and support of small businesses, and skills transfer.

Working for Wetlands was associated with the Poverty Relief-funded Working for Water programme from 2000 to mid-2003. During this time the programme was housed by the Department of Environmental Affairs and Tourism (DEAT), and received its funding from the Department of Water Affairs and Forestry, via Working for Water. In mid-2003, it was decided that WfWet should be developed and managed independently of Working for Water and the DWAF. The new, long-term home identified for Working for Wetlands was the National Botanical Institute (NBI), a statutory body associated with the DEAT, which is to be transformed into the South African National Biodiversity Institute (SANBI) upon enactment of the Biodiversity Bill. This was considered appropriate as the expanded range of functions conferred on the institute by the Biodiversity Bill included ecosystem rehabilitation, which is the core purpose of Working for Wetlands. By the end of the first quarter of 2004, NBI had developed the capacity necessary to take over full responsibility for Working for Wetlands operations. Funding for Working for Wetlands is channelled directly through DEAT.

The programme is partnered by DEAT, DWAF, Department of Agriculture, Working for Water and the Mondi Wetlands Project. These partners provide policy direction and high-level guidance, and are also engaged operationally in areas related to shared mandates. According to Dini (pers.comm.), the partnership is formalised to the extent that a memorandum of agreement exists between DEAT and DWAF regarding Working for Wetlands, and there is a formally constituted Steering Committee, consisting of all the partners, with an approved Terms of Reference. By mid-2005 a formal memoranda of agreement should be in place with all the partners (Dini pers.comm.).

WfW follows the approach of Working for Water in using a poverty relief-driven approach to its core business, the implementation of large-scale wetland rehabilitation projects. This approach has unlocked large amounts of funding earmarked by the Treasury for poverty relief.

The five ‘pillars’ of WfWetlands are:

- wetland rehabilitation;
- partnerships at national, provincial and project level;
- development of appropriate capacity;
- communication, education and public awareness (CEPA); and
- research.

An additional pillar focusing on advocacy and law enforcement will be added in the future, contingent on the logistics required to enact relevant legislation.

The rehabilitation pillar is important in the context of this project, in that objectives for rehabilitation of individual wetlands are set in conjunction with programme partners (of which DWAF is one) and have as their aim the improvement of the functioning and integrity of the ecosystem. Objectives for such projects can only be developed once there is a clear understanding of the eco-physical state of the system, the sources of impact and degradation within the catchment; and the trajectory of condition change (i.e. stable, improving or degrading). Assessment of both the function and the ecological character of a system is the most effective means of acquiring this information accurately.

Working for Wetlands’ rehabilitation planning process stands to benefit strongly from the development of a standard wetland bioassessment approach, which could be adapted to different wetland types per ecoregion.

4.2.1 Rehabilitation research

Working for Wetlands, in partnership with the South African Water Research Commission (WRC), launched a wetland-centered research programme during December 2003. The first three years of this programme will be focussed on numerous aspects of providing a scientific and technical basis for the design, implementation and evaluation of wetland rehabilitation. More details of this programme are provided in Section 4.4.

4.2.2 Wetland inventory

With support from the Norwegian government, Working for Wetlands has launched a national wetland inventory programme which will, *inter alia*, provide a clear picture of the extent, distribution and condition of South Africa’s wetlands, allow for the planning of wetland rehabilitation on a catchment scale, enable the allocation of resources (including water) to priority wetlands, and facilitate the monitoring of outcomes.

4.2.3 Prioritisation of wetlands for rehabilitation

The move to a catchment-based approach to wetland rehabilitation aligns with international best practice. The implementation of a catchment-scale approach requires the development and application of criteria for selection of priority catchments (Grundlingh et al. 2003). This meshes with the intention of Working for Wetlands to adopt a more systematic and strategic approach to the identification and prioritisation of rehabilitation interventions (WfWetland Strategic Plan 2003). One of the aims of this exercise is to optimise the ecological, hydrological and social benefits of rehabilitation projects, by grouping them in priority catchments and linking them more closely to the work being done by related programmes (Grundlingh et al. 2003).

During July 2003, the Department of Environment Affairs and Tourism (DEAT) held a one-day workshop with wetland specialists from each of the regions, to draft a set of national criteria for the prioritisation of catchments for wetland rehabilitation.

The outputs of this workshop, as tabulated below (Table 4.1), form the basis of an ongoing effort to identify and prioritise wetlands for rehabilitation nationally. A spatially-based GIS (Geographic Information System) modelling tool is to be developed as part of an ongoing Water Research Commission funded project (K5/1408), with the aim of allowing Working for Wetlands technical staff to create different scenarios for identifying and prioritising Water Management Areas (WMAs) and, if possible, tertiary catchments. The model is to be based on specific combinations of national-level, social, geographical, biological and economic criteria (Marneweck pers. comm. 2004). The output scenarios will be evaluated against specific WfWetlands (and other national) rehabilitation objectives.

Table 4.1 Preliminary criteria for the prioritisation of catchments for rehabilitation in South Africa.

National criteria	Examples of sub-criteria
Biodiversity	Biodiversity nodes/hotspots (Biodiversity map) Protected areas Threatened or priority wetlands including the peat eco-regions Ramsar sites and their catchments
Hydrological	Water stressed catchments Runoff per capita Water supply catchments Water quality at catchment scale International obligations with respect to water sharing
Socio-Economic	Nodes identified under the Integrated Sustainable Rural Development Strategy Urban renewal projects Livelihoods dependent on wetland goods and services? Poverty indicators
Threats / Impacts	New land cover map
Physical	Erodibility index Unique natural features eg. karst landscapes Density and distribution of wetlands (new Land cover wetland coverage; Cowan wetland regions)
Strategic	International rivers and boundaries Spatial development initiatives Existence of Catchment Management Agencies

4.3 MONDI WETLAND PROJECT (MWP)

Sourced from MWP website www.wetland.org.za,, Lindley (pers.comm.) and Walters (pers.comm.)

4.3.1 Background

The mission of MWP is to catalyse the wise use and rehabilitation of wetlands in South Africa. It is a combined project of the World Wildlife Fund South Africa (WWFSA) and the Wildlife and Environment Society of South Africa (WESSA), together with two funders, the Mazda Wildlife Fund and Mondi Forestry. The MWP was launched in 1991, and in the intervening years has extended its operation to cover the whole country. The project is partnered by existing structures in the government (DWAF, provindical nature conservation and agriculture agencies) and private sectors.

In the past decade, the project has assessed condition of over 30300 hectares of wetlands, and rehabilitated many degraded wetlands. A core component of the project is training of wetland managers and extension officers. MWP has played a major role in affecting government policy in South Africa.

4.3.2 The role of MWP in wetlands

MWP promotes the wise use and rehabilitation of palustrine wetlands. The focus of the project is on conservation of those wetlands predominantly outside nature reserves. This includes the majority of South Africa's wetlands.

MWP's work is divided into 8 programmes:

Wise Use Programme - catalyses the sustainable use of wetlands within the commercial agriculture and plantation forestry industries, and government departments of Agriculture, Water Affairs, Conservation, and Environmental Affairs.
Community Conservation Programme – promotes and facilitates the effective management, rehabilitation, and sustainable use of wetlands to rural tribal communities, who are usually subsistence farmers.
Integrated Catchment Management Programme – Promotes the integration of wetland management into catchment management planning, and water resource management planning.
Tertiary Education Training Programme – develops the capacity of students at Technikon education institutions studying for agriculture, forestry and nature conservation diplomas.
Rehabilitation Programme – promotes the sustainable and effective rehabilitation of wetlands that have been significantly degraded.
Lobbying and Government Co-operation Programme – persuades key decision makers and influences wetland related government policy and legislation, as well as works with government on key wetland issues.
Special Projects Programme - investigates, develops, and promotes vital wetland management tools and explores topical issues that will support the other programmes.
Publicity and Awareness Programme – produces as much publicity on wetlands as possible to make people aware of the crucial importance of wetlands.

4.3.3 The WETLAND-ASSESS Protocol

This project was commissioned by MWP in recognition of the need for, and the lack of, a standard, nationally-applicable technique for the classification and assessment of South African wetlands. Wetland-Assess is a functional assessment protocol (as against a bioassessment method) which incorporates a hydrogeomorphic classification system for South African wetlands, as modified from that developed by Brinson (1993) for use in the US. The Wetland-Assess protocol is presently in draft and testing phase (April/May 2004). The collaborators in the development of the technique included the University of Natal, MWP, Wetland Consulting Services, and Free State Nature Conservation, and the report is authored by Kotze, Marneweck, Batchelor, Lindley, and Collins (2004).

The goal of the procedure is to assist decision makers and planners at all levels to undertake rapid assessments of wetlands, recognising the wide range of existing wetland types, and for several purposes, with the focus on revealing a number of the benefits they are (or should be) supplying to society. The method is described in detail in Chapter 7, Section 7.3.

4.3.4 Development of a wetland integrity assessment protocol using plants

Mondi Wetland Project is presently collaborating with SAPPI and KZN Wildlife in the development of a wetland integrity assessment technique (Walters, pers.comm. 2004). This is intended to be a rapid technique, focusing on producing management objectives for wetlands, and for use by foresters , extension workers and similar practitioners. The output of this protocol is to be used to answer the questions: what state is the wetland in, and what is required from a management point of view to achieve the desired state?

The technique is based on a combination of an assessment of how ‘intact’ the hydrology of the wetland is, and a measure of the quality of its vegetation habitat. The health or integrity assessment method is based on the assumption that a wetland with an intact hydrology, with natural rates of sediment aggradation and degradation inhabited by indigenous vegetation is in good health. Sediment dynamics are included under hydrology.

4.4 WATER RESEARCH COMMISSION (WRC) AND PARTNERS

The WRC has a number of initiatives in wetland research, under Key Strategic Area 2 (Water-linked ecosystems):

4.4.1 Strategic assessment of research needs for wetland health integrity

This project falls within the KSA 2 Wetlands Research Programme, and is currently underway under the leadership of Dr Jenny Day (Freshwater Unit, University of Cape Town). Elements of the project are very similar to those addressed in this DWAF study. One of the study objectives is to examine questions including: what types of bioassessment schemes are being developed in different parts of South Africa and the rest of the world, which of these have merit in a SA context, what type of indices should be being investigated for use in South African wetlands, which taxa or functional groups will provide an indication of condition/deviation from reference state in which wetland types. Dr Day (pers.comm 2004) reports that for the South-western Cape wetlands studied thusfar, macroinvertebrates have not provided consistent and useful information. Different macroinvertebrate assemblages do, however, provide an indication of salinity, pH, and the temporary or permanent nature of the system. More encouraging results have, expectedly, been obtained from wetland plants (particularly rooted plants, Day pers.comm. 2004).

It is recommended that the DWAF and WRC ensure linkage between their separate initiatives regarding the assessment of wetland condition.

4.4.2 Water quality in Wetland Reserve Determination

Input from Dr Heather Malan, Freshwater Unit, UCT

In July 2002, the Freshwater Unit (University of Cape Town) commenced with a project entitled "Development of methods to determine the water quality component of the ecological Reserve for wetlands". The Project Team members on this study are Dr Jenny Day and Dr Heather Malan. The project runs until August 2004, and is concerned with assessing water quality in wetlands. The major objective is to develop methods for setting the water quality component of the Reserve for this type of aquatic resource. In other words, to derive resource quality objectives or standards for the maximum allowable concentration of chemical constituents (e.g. salts, nutrients), and the allowable range of physical variables (temperature, pH, dissolved oxygen).

These water quality objectives will need to take into account (amongst other things) the following factors:

- the type of wetland (palustrine, lacustrine, floodplain etc.)
- the natural water quality
- the level of protection that is required.

The project is confounded by the fact that wetlands are extremely variable with regard to water quality (this is both spatially and temporally). In addition there are different kinds of wetlands, and little is known of the ecological functioning of many of them. In addition, there is little water quality data (especially long-term monitoring data).

A database has been developed which contains water quality data collected from many different wetlands in the country. In addition, the Project Team is currently refining a Decision Support System of how to derive the wetland resource quality objectives for water quality.

4.4.2 Guidelines for integrating wetlands into catchment management

This project (WRC No. TT220/03) has been supported by funding sourced by Mondi Wetlands Project from the World Wildlife Fund's Living Waters Programme, through the WWF South Africa. The Project is managed by the WRC. The authors of the project report are Dickens, Mashingo, Kotze and Graham (Dickens et al. in prep).

The intention of the report is to provide a six-step guideline for the incorporation of wetland management, protection and conservation into catchment management in South Africa. It aims to provide Catchment Management Agencies (CMAs) and other agencies with a means of navigating through, and implementing, the various pieces and levels of legislation and regulations applying to wetlands in South Africa. It thus serves as a six-part guideline to the legal, institutional, technical, and social aspects of managing, protecting and conserving wetlands within a catchment management area.

Step 3 (Books 3 and 4) in the guideline includes the determination of wetland type and condition. At this stage, assessment methodologies are required. The method in the current DWAF (1999) wetland Reserve Determination process, Wetland Habitat Integrity (HI; DWAF 1999 Appendix W1) is cited. Within the present wetland Reserve method, ranges of HI scores are assigned to each of five condition categories, A-F (as per the present DWAF condition classes, currently under review). The HI can thus be used to determine Present Ecological Status (PES) of the wetland system. The authors comment that despite the method being rapid, relatively simple, and low-cost, it involves largely subjective assessment and generates no biological or ecological data, and as such is limited and requires further testing. They recommend it for use only in cursory, high-level, low confidence assessment of a wetland. The authors introduce a number of possibilities for wetland health assessments, based on overseas methods (e.g. Minnesota Index of Biological Condition; Ohio Rapid Assessment Method for Wetlands; see Section 6.2), but do not prescribe an assessment protocol or approach.

4.4.3 Wetland rehabilitation

This WRC project (No. K5/1408), Wetland Rehabilitation, falls under the WRC Wetlands Research Programme: Wetland Rehabilitation, in Key Strategic Area (KSA) 2, Water Linked Ecosystems. It is under the leadership of Prof. Fred Ellery (University of Natal, Durban). The extensive research programme is currently being tackled by a multi-disciplinary team comprising largely wetland specialists. The project addresses a number of aims in five broad groups.

- **Prioritisation of wetland areas for conservation and rehabilitation**

Development and demonstration of a framework/protocol by which wetland areas requiring conservation and rehabilitation can be continuously assessed and prioritised.

- **System Rehabilitation**

Development of a diagnostic framework for assessing wetland status and identifying the underlying causes of the degradation of individual wetland systems. Assessment of SA wetland rehabilitation case studies. Preparation of national guidelines for rehabilitation.

- **Methodologies for rehabilitation**

Case studies and evaluation of specific individual wetland rehabilitation interventions, and guidelines regarding best technical methods and management practices.

- **Synergy with other programmes**

Evaluation of various national resource management agencies and programmes on the status of wetland systems. Appraisal of the extent of interaction between different agencies and programmes in wetland conservation and rehabilitation. Highlighting of areas of concern. Guidelines to promote increased synergy between agencies and programmes.

- **Institutional arrangements**

Review and assessment of policy and legislation pertaining to wetlands, and responsibilities of government agencies and landowners regarding wetland rehabilitation. Highlighting of areas where there are institutional shortcomings. Identification and testing of approaches to secure cooperation and involvement of relevant parties can be secured

- **Performance auditing**

Includes the development of a monitoring system for use in assessing the outcomes and performance of wetland rehabilitation actions. Estimatation of cost-benefit ratios in wetland rehabilitation. Assessment of project performance, highlighting areas of concern. Provide recommendations for performance improvement.

4.5 DEPARTMENT OF WATER AFFAIRS AND FORESTRY

Wetland delineation protocol

A practical field procedure for the identification and delineation of wetlands and riparian areas has recently been produced by DWAF (2003). This manual, which is considered a ‘living' document, provides guidelines for determining whether or not an area is a wetland (as defined by NWA), and for locating its boundaries. It is the result of an extensive collaborative effort between a range of people involved, or interested in the fields of wetland research, protection and management in South Africa. The procedure requires the skills of an experienced wetland fieldworker. The manual covers the basics of wetlands and wetland values, and provides guidance for field delineation.

Guidelines for the development of a monitoring programme

There is at present no formalised wetland quality monitoring programme in SA. The Integrated Water Resource Management (IWRM) paradigm adopted by DWAF and required by the National Water Act (No. 36 of 1998) prompts the integration of the different components of the hydrological system (surface water, groundwater, wetlands, estuaries), as well as the consideration of statutory, economic, social and resource quality objectives when making a decision regarding resource use.

The DWAF Strategic Framework for National Water Resource Quality Monitoring Programmes (abbreviated as WRQMPs; DWAF 2004) assigns primary responsibility to CMAs (or DWAF Regional Offices as their substitutes) for developing '*monitoring programmes required to generate the information required to generate the information needed for determining the Ecological Reserve*' (inter alia). This represents a quantum shift from the current approach, in which DWAF Head Office is responsible for all water resource quality monitoring.

Assuming that a national wetland monitoring programme is, or will be recognised as, a requirement to meet with IWRM and NWA requirements, such a programme would have to be developed with the understanding that it would (either initially or eventually) be operated by Catchment Management Agencies (CMAs; see DWAF 2004). The assessment and monitoring methods to be used would therefore have to be tailored for use at this level (and bearing in mind a potential lack of skilled capacity within CMAs). **This is a key consideration in the decision regarding index development, as discussed further in Chapter 8 (Recommendations).**

Chapter 4 of the Monitoring Strategy provides design guidelines for the development of WRQMPs. The main phases and steps of this process are presented in Text Box 4.1 to provide clarity and direction in the eventual selection of appropriate wetland assessment and monitoring tools (see Chapter 8 of this report). These are highly summarised and the reader is directed to the original text (DWAF 2004) for the required levels of detail on each step.

Text Box 4.1 Guidelines for the establishment of a National Water Resource Quality Monitoring Programme (DWAF 2004).

PHASE I: INFORMATION GENERATION AND DISSEMINATION

Step 1:	Identify the primary users of the information
Step 2:	Identify the information products required by the primary users Consider the technicalities of producing the required information: e.g. What resource quality attributes are significant? How should these be reported (individually, in an index, etc)? What constitutes a significant difference with respect to the management issues being addressed? What format is the information required in? How frequently is it needed?
Step 3	Design the information generation protocols

PHASE 2: DESIGN THE MONITORING NETWORK

Step 1	Determine what resource quality attributes (or variables) to include in the programme
Step 2	Determine criteria for locating monitoring sites
Step 3	Determine sampling frequency

PHASE 3: DESIGN THE OPERATIONAL REQUIREMENTS FOR THE PROGRAMME

Aspect 1	Information generation and dissemination
Aspect 2	Data management and storage
Aspect 3	Data acquisition

5 INTERNATIONAL APPROACHES TO WETLAND ASSESSMENT

5.1 INTRODUCTION

The field of wetland assessment has been characterised by a rapid increase in knowledge and development of management over a relatively short period (3-4 decades). The promulgation of legislation (e.g. the Clean Water Act in the US), and the Ramsar Convention have been key drivers of this process. As a result of the development of the field, there is a wealth of literature on wetland assessment in different parts of the world, both within the formal and informal media. Not all of the documentation is, however, readily or easily accessible. The majority of information available in the more accessible media hails from the US, where wetland assessment has been regulated since the 1970s (see Section 6.3).

Within the timeframe of this project, it was decided to focus on three main international areas: the Ramsar Convention, the USA, and Australia.

- South Africa, as a Contracting Party to the Convention, has a number of obligations to fulfil in terms of the Ramsar protocol.
- The literature from the US is both well-written, based on sound science, and extensive, providing an excellent source of both summarised and detailed information on wetland assessment.
- South Africa has developed links with Australia in water resource management, and despite ecosystems being relatively different, both countries are semi arid and encounter similar levels of hydrological variability. Australia is also at a similar stage of development as South Africa, in their wetland science. The information on wetland assessment provided by the Australian agencies merits attention.

5.2 THE RAMSAR CONVENTION

A brief background to the Ramsar Convention was provided in Chapter 1 (Section 1.1). Signatories to the Convention are expected to endorse its principles, and to develop national-level policies and actions, including legislation, to ensure that the best possible use of wetlands in the context of sustainable development. In signing the treaty, Contracting Parties agree to four main commitments:

1. The designation of at least one wetland for inclusion in the Ramsar List of Wetlands of International Importance, on the basis of specific criteria and guidelines.
2. An obligation to include wetland conservation considerations in national land-use planning, so as to promote *'the wise use of wetlands in their territory'*.
3. The establishment of nature reserves in wetlands, and the promotion of training in the fields of wetland research, management and wardening.
4. International cooperation and consultation with other Contracting Parties regarding transfrontier wetlands, shared water systems, and shared species.

Each of these is addressed by a General Objective of the Strategic Plan. There are five general objectives and 21 operational objectives. Within the latter group the first objective is 'Inventory and assessment'.

As regards wetland assessment, the initial emphasis of the Convention was on providing guidance for wetland risk assessment, to assist with predicting and assessing change in the ecological character of wetlands. Resolution VII.10 on Wetland Risk Assessment (see Finlayson et al. 2001) adopted a framework that provides guidance on how to go about predicting and assessing change in the ecological character of wetlands. While this framework provides for a protocol which is somewhat different to that required for ecological or biological assessment, it does emphasize the usefulness of early warning systems, which would likely be represented by bioassessment protocols.

The 6-step risk assessment model was modified from a generalised ecological risk assessment (ERA) model, and is based on concepts presented by van Dam et al. (1999):

1. ***Identification of the problem:*** identify the nature of the problem and develop a plan for the remainder of the assessment, including the objectives and scope.
2. ***Identification of adverse effects:*** determine the types of adverse ecological and/or socio-economic effects caused by the problem.
3. ***Identification of the extent of the problem:*** estimate the extent to which the problem may or does occur.
4. ***Identification of the risk:*** integrate the results from the above steps.
5. ***Risk management and reduction:*** make decisions to minimize the risks without compromising other societal, community or environmental values.
6. ***Monitoring:*** verify the effectiveness of the risk management decisions.

The application of the above risk assessment model has been demonstrated in specific case studies for invasive species (Finlayson et al. 2001c, van Dam et al. 2001) and altered water allocations within a river basin (Begg et al. 2001). It is anticipated that further assessment procedures will be developed or expanded to support this risk assessment model. Importantly, it is noted that the risk assessment model builds on information obtained through the inventory procedure, and this is linked with monitoring (Step 6).

All of these requirements emphasize the need for an empirically-derived baseline understanding of the country's wetlands – both in their natural and present states - in terms of their type, locality, distribution, function, ecological character, and sensitivity. It is important to develop a 'reference condition' for each type of wetland, and to have some knowledge of the degree to which the present state of wetlands within that category deviate from reference. The development of functional and bioassessment methods are fundamental to the gathering of this type of information.

5.3 USA

The United States has taken an increasingly aggressive stance on wetland loss in the past three decades. Thirty years ago, the country was losing almost 500,000 acres of wetlands per year. It is now nearing the national goal of 'no net loss' of wetlands, which was reaffirmed by President Bush in 2002. This year, the President announced a new national goal, to have an *overall annual increase* of wetlands in America, through the creation, improvement and protection of at least three million wetland acres over the next five years (Whitehouse Press Release, 22 April 2004).

The country has sound legislation backing these intentions. The federal government is responsible for protecting the nation's wetlands, in terms of two laws:

- The River and Harbors Act (1899), which provided the US Army Corps of Engineers with the necessary permission for any construction involving dredging, filling or obstruction of navigable waters, but did little to protect wetlands, other than those that are navigable.
- The Federal Water Pollution Control Act, more commonly known as the Clean Water Act, which gave the federal government authority over wetlands. This Act includes the Corps' 1968 revision of permit regulations, in response to increasing national concern for the state of the nation's natural resources. In this revision, all developments potentially affecting wetlands are required to be evaluated before a construction permit is issued. The effect of the proposed work on navigation, fish and wildlife, conservation, pollution, aesthetics and the interest of the general public is assessed. The exemptions from the wetland protection laws include farming activities including roads associated with farming and the construction or maintenance of farm ponds, irrigation or drainage ditches; maintenance of structures such as dikes, dams, levees, etc.; construction of temporary sedimentation basins on construction sites; forest roads or temporary roads for moving mining equipment (Maine State Planning Office 2001).

The 1972 amendments to the Clean Water Act extended the US Army Corps' regulatory jurisdiction to cover all waters of the United States, including wetlands. This authority is listed in Section 404 of the Clean Water Act, and certain activities in wetlands are permitted under what is commonly known as "404 Permit." The Corps "404 Regulatory Programme" undertakes the permit review process, which requires an **assessment of the effect of a project on wetland *functions*.** This was the principle driving force behind the development of wetland functional assessment methods in the US.

The US Environmental Protection Agency (EPA) was made a partner in the 404 Programme, giving them veto authority and responsibility for establishing guidelines for protection of aquatic environments. Under these requirements, the agency is required to develop imporvied monitoring and assessment methodologies for aquatic ecosystems and their associated landcapes. The US EPA has a national research strategy on the Environmental Monitoring and Assessment Programme (EMAP) run by the Office of Research and Development, as well as a Biological Monitoring Programme that operates at the state level and is coordinated by the USA EPA Office of Water. The US Geological Sruvey (USGS) operates the North American Water Quality Assessment (NAWQA) Programme (US EPA 1998).

EMAP and NAWQA make assessments of the environment and trends in quality at both national and regional scales. EMAP has not yet selected a single approach to sampling wetlands. The most commonly used approach is the multimetric approach, as it allows for the integration of ecological information with the elements and processes of naturally-functioning aquatic assemblages (e.g. Butcher 2003).

5.3.1 US EPA National Wetland Programme

In 1999, the US EPA National Wetland Programme made the establishment of comprehensive state and tribal wetland monitoring programmes a national priority. The following spring, a national wetland monitoring strategy was developed. The focus on collection of scientifically sound and geographically-comparable data is ensured through ongoing coordination with states and tribes (US EPA 2004). The aim of establishing monitoring programmes throughout the country was to address the lack of baseline environmental data, for a number of reasons: to determine whether resources were being effectively allocated, and to ensure that the outcomes of wetland protection and restoration measures could be meaningfully assessed to ensure that these actions were resulting in environmental improvement.

5.3.2 US approaches to wetland assessment

In the early 1970s, assessment procedures were designed for use on large controversial planning projects or wetland inventories, and they focussed on a narrow set of wetland functions and social values (benefits). In 1980 the US Fish and Wildlife Service produced a Habitat Evaluation Procedure (HEP) which examines the quality and quantity of available habitat for selected species (USFWS 1980). This is still in use (Bartoldus 1999). By the 1980s, there was a growing need for rapid assessment of wetlands to fulfil regulatory projects of varying sizes. This gave rise to the development of the Wetland Evaluation Technique (WET) of Adamus et al. (1987). Later, in response to the US Army Corps' need for an assessment technique which would facilitate meeting the technical requirements of the '404 regulatory programme', the Hydrogeomorphic (HGM) classification was developed (Brinson 1993) and within a couple of years was incorporated into a Hydrogeomorphic assessment protocol (Smith et al. 1995). This provided a framework within which regional and wetland-type specific assessment models could be developed (Bartoldus 1999).

Functional Assessment:
The Hydrogeomorphic (HGM) Approach

(Sourced from Bartoldus 1999, Smith et al. 1995, Brinson 1993)

Four basic hydrogeomorphic classes (and several subclasses) of wetlands are recognised in the HGM approach:
1) Depressional wetlands
2) Extensive peatlands
3) Riverine wetlands
4) Fringe wetlands.

Each type has a distinctive combination of hydroperiod, dominant direction of water flow, and vegetation zonation.

In assessment, wetlands are first classified into one of these groups, on the basis of three hydrogeomorphic properties: **geomorphic setting, water source** and **hydrodynamics.** Each of these has associated ecological significance. The functions which are then assessed for each wetland type are derivatives of these three properties. These fall into one of three major categories of function: **hydrologic** (e.g. storage of surface water); **biogeochemical** (e.g. removal of elements and compounds); and **physical habitat** (e.g. topography, depth of water, number and size of trees).

The development of 'functional profiles' for different wetland types reveals both the major functions of the wetland type, and the hydrogeomorphic bases for these. The output of the method is a measure of the functional capacity of a wetland site relative to wetlands from the same regional wetland subclass.

HGM is applicable to all wetland types, but the assessment model must be developed specifically for wetlands within a regional subclass. Results cannot be compared with those of wetlands from different subclasses or different regions. As yet, not all assessment models have been developed.

There are two main phases in the procedure. The first phase, **Development,** has five steps. (i) The wetlands are first classified into regional subclasses based on their hydrodynamics, water source and geomorphic setting. (ii) A multidisciplinary specialist team identifies the variables for the assessment procedure; direct or indirect measures of these variables are listed; a sub-index scale (from 0.0 to 1.0) is assigned to conditions for each variable; and an equation for calculating the functional capacity index (FCI)[3] is devised. Functions are then measured across the selected set of wetlands, to determine the range of performance for those functions in wetlands within the landscape. These measurements are used to create ***functional profiles*** *(*which reveal the functions that the wetlands are likely to perform). The profiles are used to develop the ***functional indices*** which estimate the capacity of a wetland to perform a function relative to other wetlands of the same HGM type in the reference domain. (iii) Reference wetlands are then identified. (iv) On the basis of the aforegoing, an assessment model for the relevant regional subclass is developed by the specialist team, and an assessment guidebook is produced. (v) The final step is to calibrate the assessment model using the reference wetlands. This first phase could take months of work for each regional wetland subclass.

In the second phase, **Application**, the assessment model is applied in the field in a 3-step process: (i) In the first step, *characterisation*, the assessment objectives are defined, the wetland landscape is described and screened for 'red flags' (obvious and immediate threats). (ii) In the second step, *assessment*, assessment models for each function are applied to each wetland assessment area (WAA). Models contain information on several variables (V). The conditions best reflecting the WAA are selected and the corresponding variable subindex (as read off a graph) is recorded. The subindices are then used in equations to calculate the Functional Capacity Index (FCI). From this score, the Functional Capacity Units (FCUs) are determined by multiplying FCI by the area of the wetland assessed. Results are then recorded in summary tables. (iii) In the third and final step, *analysis**,*** the assessment results are analysed for specific applications.

The protocol is subjected to peer review and public comment before the model is finalised. It provides an objective means by which functional performance can be measured, objectively compared across geographic areas, and evaluated.

According to Thiesing (2001), one of the greatest strengths of the HGM approach is that the process of developing the model is an iterative one, which allows for refinement and validation based on data and expert review. As a technique, it is both objective and quantitative, and uses reference wetlands to provide objective bases for standards of comparison. Although the development of the model is costly, once it is achieved, the assessment of any wetland would be expected to be rapid, consistent and reproducible. Thiesing (2001) notes that the disadvantages are that the results of the assessment and the functions measured tend to be obscure and complex, and may not capture functions of importance as defined by established management objectives. It also does not evaluate highly impacted wetlands (e.g. those in urban settings).

Further functional assessment methodologies

As wetland assessment methods are increasingly required to meet regulatory, management and social requirements, an extensive array of procedures has been developed across the country, to provide a means of identifying, characterising and measuring wetland functions and/or social benefits. Bartoldus (1999) reviews 40 assessment methods, each developed to

[3] FCI is an index of the capacity of a wetland to perform a function, relative to other wetlands within a regional wetland subclass in a reference domain. A score of 1.0 indicates optimal function, equivalent to a reference condition wetland in the same reference domain. A score of 0.0 indiates that the wetland does not perform the function at a measurable level, and will not recover the capacity to perform the function through natural processes (Bartoldus 1999).

meet a specific set of needs. She points out that *'the availability of all these procedures presents a mixture of fortune and confusion. While wetland scientists are fortunate to have these tools available, there is confusion about what procedures are available and how they work'*. Of the suite of available methods, the majority were developed to assess wetland *function* rather than to assess *biological integrity.* While the former represent a critical information source in the development of wetland assessment methods in South Africa, more detailed discussion of these methods is of limited value to this project for two reasons. Firstly, these methods exclude direct measures of biological condition, which is the principal focus of this project, and secondly, a specialist South African wetland team (Kotze et al. in press) has already extensively reviewed these methods and is in the process of testing their functional assessment method WETLAND- ASSESS (described in Section 7.3.2).

The remainder of this section on the US situation is focussed on their approach to bioassessment protocols.

Biological Assessment :
The Biological Assessment of Wetlands Workgroup (BAWWG)

In the mid-1990s, changing resource management needs and growing awareness in the wetland field prompted interest in developing methods to assess the biological integrity of wetlands, and to evaluate the consequences of human actions on biology of these systems. Bioassessment methods were developed essentially for use in the various activities associated with managing aquatic resources (Bartoldus 1999). In 1997, the Biological Assessment of Wetlands Workgroup (BAWWG, pronounced "bog") was formed, with the objective of improving methods and programmes to assess the biological integrity of wetlands (EPA 1998c). By January 1998, BAWWG comprised wetland scientists from six federal agencies, six states and seven universities. It is coordinated by EPA Office of Water, Oceans and Wetlands (OWOW), and the EPA Office of Science and Technology. The group meets periodically to examine issues related to the development of wetland bioassessment methods and protocols: e.g. the selection, scoring and testing of metrics, the combination of metrics into an integrated index of biological integrity (IBI), the definition of reference conditions, the development and testing of sampling methods, and when and how to sample each assemblage.

BAWWG has focus groups for five taxonomic assemblages:

- macroinvertebrates,
- vascular plants,
- amphibians,
- algae, and
- birds.

A sixth focus group examines the relationship between assessing wetland biological integrity and the hydrogeomorphic (HGM) approach to assessing wetland functions (US EPA 1998f). This is of particular interest to this project, as it focuses on identifying similarities and differences between the two methods and identifying ways that the two approaches can support one another (US EPA 1998f). Table 5.1 lists some of the wetland bioassessment projects conducted by BAWWG members.

Table 5.1 Some of the wetland biological assessment projects conducted by members of the BAWWG. *From US EPA (1998d).*

AGENCY	ANALYTICAL METHODS	SPECIES ASSEMBLAGES	PROJECT PURPOSE	WETLAND TYPE	STRESSORS AFFECTING WETLANDS
Minnesota	Index of Biological Integrity (IBI)	Vascular Plants Macroinvertebrates Amphibians	Water quality standards	Depressional semipermanent with emergent vegetation	Agriculture Storm water runoff
Montana	Attempting to develop bioassessment protocols using both multimetric and multivariate approaches	Macroinvertebrates Algae (diatoms) Vascular Plants	Water quality standards	Depressional Riparian/fen Closed basins Open lakes	Agriculture Mining Others
Minnesota	* Floristic Quality Assessment Index (FQAI) for vascular plants * IBIs for both amphibians and macroinvertebrates	Vascular Plants Macroinvertebrates Amphibians	Water quality standards	Depressional Riparian	Agriculture Development Others
North Dakota	IBI	Macroinvertebrates Algae Vascular Plants	Water quality standards	Depressional (prairie potholes)	Agriculture
Patuxent Wildlife Research Center (USGS and NRCS)	Investigating use of each assemblage for bioassessments	Macroinvertebrates Vascular Plants Birds Fish Amphibians	Evaluating performance of wetland restoration	Depressional (Delmarva Bays) in various stages of succession	Restored wetlands on agricultural land compared to minimally disturbed wetlands
U.S. EPA Duluth Lab	IBI	Macroinvertebrates Vascular Plants Algae	Water quality standards	Depressional (prairie potholes)	Agriculture
U.S. EPA Corvallis Lab	Analysing survey design and reporting methods	N/A	Evaluating wetland program effectiveness	Various wetlands located in mid-Atlantic region	Mixed land use
USGS Northern Prairie Science Center	Has collected some macroinvertebrate data in conjunction with HGM project	Macroinvertebrates	Supplementing HGM* project	Depressional (prairie potholes)	Agriculture Others

USGS = US Geological Survey
NRCS = Natural Resource Centre

Where appropriate, methods referred to here are discussed in more detail in later chapters.

According to US EPA (1998d, updated January 2003), individual BAWWG members are still in the preliminary stages of identifying and testing potential metrics, particularly for birds, amphibians, plants, and algae. Most current research is being conducted on macroinvertebrates and vascular plants in depressional wetlands with emergent and submerged vegetation. Further research is needed in other wetland types, especially in wetlands that have saturated soils but lack standing water for most of the year.

5.3.3 The National Wetland Monitoring and Assessment Workgroup

The National Wetland Monitoring and Assessment[4] Workgroup was established to ensure that wetland monitoring and assessment were integrated into states' and tribes' watershed monitoring strategies (which also address rivers, streams and lakes). The group comprises agency managers and scientists working for the US EPA or the states and tribes. Through the development of policy and guidance, this group assists states and tribes to develop capacity to undertake monitoring and assessment activities which support wetland protection and restoration. A set of documents has been developed by the EPA to provide states and tribes with information to assist in the development of wetland bioassessment methods, with a focus on evaluation of both the overall condition of wetlands, and nutrient enrichment of systems. A number of modules in this series are designed to assist states and tribes in the development of biological and water quality criteria for wetlands (US EPA 2004)

5.3.4 Relevance of US approaches to this project

The history of wetland assessment in the US provides South Africa with a wealth of transferable information and experience, and represents a means of avoiding lengthy research and development phases in our own establishment of assessment protocols. The size, budgets, policy tools, and sophisticated agency structures of the US have facilitated growth field of wetland science, conservation and protection, such that it is many years ahead of South Africa and other countries. Despite the fact that the major driving force behind the development of assessment protocols was the Clean Water Act and the '404 Regulatory Programme', neither of which entirely correspond to our own policy tools, the outcomes represent a series of generic approaches to wetland assessment, many of which could be (and are) modified and applied anywhere in the world.

The area of relevance in the US, for the purposes of this project, is that of increasing research and development interest being directed towards development of bioassessment protocols for wetlands. A decade ago, in the development process leading up to the launch of the South African National River Health Programme, the specialist scientific team recommended the use of a series of biomonitoring indices for fish, invertebrates, and riparian vegetation in South Africa rivers. The suggestion was that a scenario-based approach was followed, wherein one or more methods were used depending on the scale of the monitoring exercise, the budget available, and the human resource capacity. Methods were to be selected sequentially from the prioritised protocols. All of these methods had been developed to some extent already, and most were based either directly or indirectly on existing international (largely US) biomonitoring methods (Uys et al. 1996). The River Health Programme has been successfully monitoring South African rivers and producing 'State of the Rivers' reports for over a decade now. The methods which were recommended have been adjusted and refined, following the principle of adaptive management. As the model has been successful, the same sort of 'loaning' of conceptual approaches would likely be effective for wetlands, and should be strongly considered.

[4] As discussed earlier in this report, no explicit definitions have been located to establish how the US EPA and other agencies differentiate between wetland 'assessment' and wetland 'monitoring'. It seems that the term 'monitoring' refers to the act of measuring condition, while the term 'assessment' refers to an evaluation of wetland condition based on the data and information acquired in the monitoring process.

5.4 AUSTRALIA

It is estimated that since European settlement, approximately 50% of Australia's wetlands have been converted to other uses. In some regions, the rate of loss has been even higher. For example, on the Swan Coastal Plain of Western Australia 75% of the wetlands have been filled or drained, and in south-east South Australia 89% have been destroyed.

5.4.1 National Wetland Policy

Australia was the first Contracting Party to the Ramsar Convention. The Biodiversity Group of Environment Australia was the designated administrative authority for implementation in Australia of the Ramsar Convention, and in 1995 began the process of preparing a National Wetland Policy. A National Wetlands Advisory Committee was established in July 1995 to advise the Commonwealth Minister for the Environment on the Policy. The Australian Commonwealth Government is responsible for the management of significant areas of Australia's wetlands, and administers numerous social, economic and environmental programs that impact on wetland conservation and use throughout the country (Australian Wetland Policy 1997). The Natural Heritage Trust (NHT) of Australia serves as the national coordinating agency for the development of cooperative arrangements with States, Territories and local Governments and the community regarding implementation of the Policy.

The Policy has six strategies to provide for the conservation, repair and wise use of wetlands:

1. Managing wetlands on Commonwealth lands and waters.
2. Implementing Commonwealth policies and legislation and delivering Commonwealth programs.
3. Involving the Australian people in wetlands management.
4. Working in partnership with State/Territory and local Governments.
5. Ensuring a sound scientific basis for policy and management.
6. International actions.

Strategy 5 aims to, inter alia, 's*upport and promote the development of expertise for a sound technical and scientific basis for wetland conservation and management'.* Two of the three mechanisms identified to achieve this are:

Monitoring the state of wetlands:

- compiling and regularly updating a national wetlands inventory;
- developing national guidelines, protocols and benchmarks for the short and long-term monitoring of Australia's wetlands;
- devising means to ensure regular monitoring of wetlands; and
- providing State of Environment on the extent and condition of wetland resources;
- Developing and supporting a strategic and coordinated wetlands research effort
  This includes:
  - Continued development of Commonwealth funded wetland-related research (e.g. through the National Wetlands Research and Development Programme);
  - Fostering priority research to address wetland management issues, e.g. clarifying the taxonomy and distribution of wetland-dependent species; and improving information held on the migration and distribution patterns of migratory waterbirds.

5.4.2 Directory of Important Wetlands (DIWA)

The DIWA is a cooperative project between the Commonwealth, State and Territory Governments. It identifies nationally important wetlands, providing information on their variety *and the dependent flora and fauna.* It does not provide detailed information on each wetland.

5.4.3 National Water Quality Management Strategy, and Australian Guidelines for Fresh and Marine Waters

The purpose of the National Water Quality Management Strategy is to protect and enhance the quality of water resources, while maintaining economic and social development.

The ANZECC & ARMACANZ (2000) guidelines provide a series of protocols for assessing and monitoring water quality, some of which require further development and testing regarding their suitability in wetlands. The use of macroinvertebrates in assessment and monitoring is strongly supported: "*On balance and where it may not be immediately obvious as to the choice of biodiversity indicator to apply to streams, wetlands and lakes, macroinvertebrate communities probably represent the most broadly applicable group"* p8.1-22.(cited by Butcher 2003). Butcher (2003) comments that these guidelines provide a possible framework for developing a wetland assessment and monitoring program, although the majority of the developmental work is still required to apply techniques and protocols successfully in wetlands.

5.4.4 Monitoring and assessment of wetlands

Only certain of the objectives listed in Strategy 5 of the National Wetland Policy appear to have been fulfilled at a state and territory level. The most comprehensive review of wetland assessment activities in Australia is provided by Butcher (2003) in her report to the Victoria State Water Quality Monitoring and Assessment Committee (SWQMAC), regarding the options for establishing a programme for assessment and monitoring of wetland condition in Victoria.

Butcher (2003) reports on wetland monitoring and assessment activities in the states and territories of Australia, as informed by a network of contacts across Australia, and extensive literature review. At the time of her report, no statewide wetland condition monitoring programmes had been initiated in ACT, New South Wales, Victoria, Northern Territory, Queensland, Tasmania or Western Australia. The closest initiative is that of the Western Australian Department of Conservation and Land Management (CALM), who monitors 25 wheatbelt wetlands for biodiversity, and 100 for depth and some aspects of water quality. This includes assessment of waterbirds, vegetation condition and groundwater monitoring, and invertebrates. The program focuses on measures of biodiversity rather than health, acknowledging the difficulty in defining 'health' with such a diverse range of wetland types in WA. The Water and Rivers Commission in WA also has an long-standing program of once-off inventory (mapping) and desktop assessment of wetlands (based on existing information; Butcher 2003).

A number of other initiatives in the individual states are described. It should be noted that new programmes may have come into existence subsequently, but no information to suggest this has been forthcoming in the current review. Butcher (2003) reports that in Queensland, floodplain frogs are being sampled by the state government agencies, as indicators of floodplain health. Large storages are being monitored for phytoplankton. Research projects continue to investigate ecological character and responses to various perturbations.

In New South Wales, the focus of wetland assessment is Integrated Monitoring of Environmental Flows (IMEF) program, which is the largest wetland assessment effort in the state. South Australia has published a draft Wetland Strategy that provides an assessment of the state's wetland resources, but does not provide protocols for assessing and monitoring wetland health. Regional wetland inventories have also been completed for South Australia, providing baseline once-off survey type data from which a broad assessment of condition has been made for each region, for the purposes of selecting a subset of wetlands considered to have high conservation value and to be included in a further monitoring program. Tasmania had recently undertaken an assessment of the condition and status of Tasmania's wetlands and riparian vegetation.

5.4.5 Transferring rapid assessment approaches for rivers to wetlands

The view point that rapid assessment methods designed in use in rivers can be transferred for use in streams is one which is widely supported by many who have been involved with the AUSRIVAS river biomonitoring program in Australia (see Butcher 2003). RIVPACS is a predictive modelling technique developed in the United Kingdom as a tool for the biological assessment of stream condition using macroinvertebrates. The predictive modelling approach used in RIVPACS forms the basis of AUSRIVAS, which has successfully assessed the condition of several thousand sites around Australia (Parson et al. 2002).

A report (undated) entitled 'Monitoring wetland health: are National River Health Program protocols applicable?' was recently funded by the National Wetlands Research and Development Program, Land and Water Australia (LWA, then LWRRDC), Environment Australia and the Waters and Rivers Commission of Western Australia. The senior specialists on the project team were Davis, Horwitz, Norris and Chessman, all of whom have extensive experience in aquatic ecosystem assessment.

The objectives of the study were:

- to determine the validity of applying a predictive model, incorporating macroinvertebrate and environmental data, and reference and test sites, to the monitoring and assessment of Australian wetlands (such models have been widely applied in the monitoring and assessment of Australian rivers);
- to develop a National Wetland Bioassessment Protocol similar to the National River Bioassessment Protocol.

The study team developed a combined habitat and season model, similar to those developed for Australian rivers, using an existing dataset collected during three sampling sessions of the Swan Coastal Plain during spring of 1989 and 1990 (using random sampling and laboratory identification of invertebrates). Four main groups of reference sites were identified as part of the model construction process. Predictor variables for these groups were identified statistically as calcium, colour (gilvin), latitude, longitude, sodium and organic carbon. AUSWAMP was tested in 1997 on 23 wetlands in the Swan Coastal Plain, near Perth in Australia.

The authors report that model results for wetlands sampled using a rapid bioassessment protocol were not significantly different from the results obtained with an earlier random sampling of the test sites, in which invertebrate material had been laboratory-processed. This suggested that a rapid protocol was acceptable in situations in which rapid and cheaper assessment were required.

Wetland habitats (particularly plant communities) were found to be important in determining the composition and richness of invertebrate communities. The authors commented on the implications of this finding for the design of macroinvertebrate biomonitoring protocols, and the associated need for a separate method for the rapid assessment of wetland condition based on the composition and abundance of submerged, emergent and fringing vegetation. The recommended format for this was the development of a protocol for wetland habitat assessment (focusing on vegetation) to be used in conjunction with the rapid bioassessment protocol. This would enable inferences to be made as to whether a low invertebrate bioassessment score reflected poor water quality or poor habitat condition, or both.

Text Box 5.2 Key features of the macroinvertebrate bioassessment protocol, AUSWAMPS, designed for use in Australian wetlands

- Sampling is conducted during the period of maximum water level (varies with climatic zone).
- The recommended minimum number of sites per wetland is four (to represent the biotic heterogeneity present in fairly healthy wetlands), and these should be positioned approximately in the north, south, east and west sectors of the site.
- Only two major habitats, which are likely to be present in the majority of wetland types, are sampled: submerged macrophytes (which may include bare substrate), and emergent or fringing macrophytes (sedges and rushes).
- Separate sampling and modelling of submerged and emergent plant habitats is preferred to address the difficulty of predicting what the extent of each type of habitat will be in a particular wetland, in a particular year.
- Invertebrate samples are collected within an approximately circular or elliptical wetland, in each of the two habitats and the four sectors. Larger, or long, linear wetlands may need to be subdivided into two or three sections, and each assessed separately, to ensure adequate characterization.
- For wetlands of high conservation value, or of particular management concern, the collection of environmental data at monthly, or bimonthly intervals, is also recommended. Rapid bioassessment and use of a rapid habitat assessment protocol provide useful instantaneous information. However, the collection of continuous records for parameters such as wetland depth is also important to characterise wetland condition and environmental change. Ideally, regular monitoring of simple physical and chemical variables (conductivity, pH, colour and turbidity) and nutrients should also be conducted, particularly if nutrient enrichment is a major management issue.

The authors concluded that a rapid bioassessment approach, using macroinvertebrates as an indicator group, was a useful technique for wetland assessment and monitoring, particularly when a suite of analyses rather than a single approach, was used. On the basis of their results, the authors advocated predictive modelling as a potentially useful tool in the assessment of the impact of groundwater abstraction on wetland ecosystems, and other impacts, provided sufficient reference wetlands were sampled to adequately characterise the natural variation in wetland water regimes.

In comparing AUSWAMP with other bioassessment methods, an important revelation was that the different methods provided different information on wetland condition. For instance some of the AUSWAMP metrics were significantly correlated with pH and depth of sampling sites, but were not significantly correlated with any indices of disturbance. In comparison, the biotic index SWAMPS (described in Section 6.2), was significantly correlated with pH and log total Phospate. SWAMPS values were significantly correlated with all disturbance indices except sediment contamination. Taxa Richness (number of families) was significantly correlated with contamination.

The authors' further recommendations for future effective management of wetlands included the further refinement of the biotic index, SWAMPS, to provide a eutrophication index for wetlands; and development of a protocol for wetland plant habitat assessment to compliment information provided by rapid bioassessment using invertebrates (to include an assessment of the extent and condition of submerged, emergent and fringing vegetation).

5.5 ASIA

Although little information was accessed on wetland assessment in Asia, a framework has been developed for wetland inventorising, assessment and monitoring (WIAMS) in Asian wetlands, particularly those in Malaysia. This is outlined in Appendix B, as a context within which to examine bioassessment method development for South African wetlands. According to Butcher (2003), this framework was developed in close association with the Ramsar Convention, such that it is applicable on a global to local scale. The method focuses on the use, functions and attributes of wetlands. Of interest to this project is Step 4 of the process, in which the user is directed to choose an appopriate method for the specific assessment need, out of four general approaches: Desk study assessment, Rapid Assessment, Data-driven assessment and Bioassessment (using an Index of Biotic Integrity).

5.6 MEDITERRANEAN

The degradation and loss of the rich resource of extensive wetlands of the Mediterranean region was recognised in a major wetland conference in Grado, Italy in 1991. This led to the initiation of a Mediterranean wetland initiative known as MedWet, in 1992. The intention behind the programme was to develop methods that could potentially improve wetland conservation in the Mediterranean region, with an emphasis on addressing and halting further loss and degradation, and ensuring the wise use of wetlands (Costa et al. 2001). One of the actions within MedWet was the development of methods for inventory and monitoring of wetlands. Owing to the diverse nature of the region and the resources available, it was necessary to design a method which was flexible in terms of the level of detail required, and adaptable to a range of different situations and requirements. The inventory tools developed, which include guidelines, datasheets, a habitat description system, mapping conventions and database software, have been field-tested sites in each of the five European Mediterranean countries and in Morocco and Tunisia (Costa et al. 2001). No information was found regarding the development of monitoring and assessment protocols for MedWet.

6 VARIABLES USED IN THE ASSESSMENT OF WETLAND CONDITION

6.1 INTRODUCTION

There are three broad groups of variables typically used in the assessment or monitoring of wetland environmental condition: functional, physical and biotic. The choice of which (or which combination) to use depends on the purpose of the assessment, and the application to which the output information will be put.

Typically, functional assessments evaluate the level at which different wetland types perform different functions, relative to a predetermined type-specific reference condition. These are a necessary form of wetland assessment in the US, to ensure compliance with the '404 Regulatory Programme', a permit review process for any new development likely to impact on a wetland system. This process requires that an assessment of wetland function be undertaken (see Section 5.3.2).

Physical variables are used to describe the ecological character of the wetland, and may include: water regime, water source, geomorphic setting, area, length, bathymetry (including average and range of water depth), and substrate or soil composition (Butcher 2003). The last of these is crucial in providing an understanding of the historic wetland wetting regime, and how it may differ from present day. This is a core element of wetland delineation and classification, and a key to understanding present wetland biota.

Biological variables are used in bioassessment and monitoring. They include different plant or animal taxa, or communities thereof. The five groups of taxa referred to in bioassessment of wetlands are: plants (with algae as a separate group), aquatic macroinvertebrates, waterbirds, amphibians, and fish (Butcher 2003, Bartoldus 1999, US EPA 1998c). More than one biological variable is often used in assessment, as different elements of the biota correlate with different physical or chemical variables or stressor types.

As the focus of this report is on the development of an integrated *biological* assessment protocol for the evaluation of wetland condition, the five groups of individual biotic variables listed in the former paragraph will be discussed in detail here. As soil is the physical variable most commonly used to establish the wetland type and regime in the field, and is critical in providing a context for understanding biological conditions, this is also described.

6.2 SOIL

This section authored by Gary Marneweck

Probably the most widely used international definition of a wetland, that of Cowardin et al. (1979), defines wetlands as "lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water". These authors further emphasise three key attributes of wetlands; i) hydrology; ii) the presence of hydrophtes; and iii) hydric soils. The National Research Council (1995) definition of a wetland states that "a wetland is an ecosystem that depends on constant or recurrent, shallow inundation, or saturation at or near the surface of the substrate. The minimal essential characteristics of a wetland are recurrent, sustained inundation, or saturation at or near the surface and the presence of physical, chemical, and biological features reflective of recurrent, sustained inundation or saturation. Common diagnostic features of wetlands are hydric soils and hydrophytic vegetation. These features will be present except where specific physiochemical, biotic or anthropogenic factors have removed them or prevented their development".

6.1.1 Soil as an indicator of the wetting regimein wetlands

All these definitions make specific reference to saturated soils and/or the nature of soil development, and plants adapted to, or living in saturated soils. The saturation of soil, particularly where it is prolonged such as in wetlands, has a characteristic effect on soil morphology, affecting soil matrix chroma and mottling in particular (Natural Resources Conservation Service 1995). Mottling refers to the variegated colour patters seen in the saturated horizons of the soil as a result of the solution and precipitation of mainly iron and manganese in response to variations between anaerobic and oxidised states.

Matrix refers to the "background colour" of the soil while chroma is defined in terms of the relative purity of the spectral colour, which decreases with increasing greyness. All these factors are influenced by variations in wetness in the soil profile, the extent and duration of saturation of the soil, and the nature and type of soil or substrate present, producing characteristic features, or distinctive colouring, staining and in some cases even odour in the profile (see Figure 2, *Criteria for using soil morphology as an indicator of hydric conditions,* in Kotze and Marneweck, 1999). Where detailed hydrological data are not available for a specific site, hydric indicators in the soil profile are therefore the most reliable indicators of the long-term wetting regime.

6.1.2 Using soils and vegetation as indicators of the wetting regime in a wetland

Wetlands and zones within a wetland can be permanently, seasonally or temporarily wet. This means that either the entire wetland, or different zones within a wetland, can range from being permanently flooded or saturated for the entire year every year to being flooded or saturated for only a few weeks in a year, to being flooded or saturated only every few years. A diagnostic feature of wetlands or zones within a wetland, is, that even if they are temporarily wet, they need to be wet for long enough to develop anaerobic conditions. Together soil and vegetation criteria can be used to establish the wetting regime within a wetland or within zones in a wetland (Tiner 1999). Kotze et al. (1994) developed a set of criteria for vegetation and soils to assist with identifying the degree of wetness in wetlands (Table 6.1).

Table 6.1 Criteria for distinguishing different degrees of wetness within a wetland [as modified from Kotze, Hughes, Breen and Klugg (1994)].

SOIL	DEGREE OF WETNESS		
	Temporary	**Seasonal**	**Permanent / Semi-Permanent**
Soil depth 0-10 cm	Matrix brown to greyish brown (chroma 0-3, usually 1 or 2) Few/no mottles Nonsulphidic	Matrix brownish grey to grey (chroma 0-2) Many mottles Sometimes sulphidic	Matrix grey (chroma 0-1) Few/no mottles Often sulphidic
Soil depth 30-40 cm	Matrix greyish brown (chroma 0-2, usually 1) Few/many mottles	Matrix brownish grey to grey (chroma 0-1) Many mottles	Matrix grey (chroma 0-1) No/few mottles Matrix chroma: 0-1
VEGETATION	**DEGREE OF WETNESS**		
	Temporary	**Seasonal**	**Permanent / Semi-Permanent**
If herbaceous:	Predominantly grass species; mixture of species which occur extensively in non-wetland areas, and hydrophytic plant species which are restricted largely to wetland areas	Hydrophytic sedge and grass species which are restricted to wetland areas, usually <1m tall.	Dominated by: (1) emergent plants, including reeds, sedges and bulrushes, usually >1 m tall; or (2) floating or submerged aquatic plants.

For more detailed application such as in Reserve Determinations, this can be taken one step further. The broad vegetation categories shown at the bottom of Table 6.1 can further be divided into functional groups made up of species with similar life-history attributes/characteristics. The specific life-history strategies may differ between and within functional groups but the characteristics associated with the strategies may be similar. For example, submerged or floating aquatic plants associated with permanent and semi-permanent zones within a wetland may survive droughts (when there is no surface water in the system) via desiccation resistant propagules such as turions while hydrophytic grasses associated with seasonal zones may survive via desiccation resistant rhizomes. Understanding these strategies and associated attributes will assist with defining the frequency of wetting that may be required to sustain certain populations. Similarly, an understanding of the growth response of a species to indundation for example, will assist with determining depth and duration requirements, etc. By identifying individual indicator species and/or functional groups of indicator species, and by establishing their spatial zonation, a specialist can then use soil indicators and the life-history attributes to assist in establishing a specific flow regime (depth, duration and timing of inundation or saturation) for any area or zone within the wetland system.

6.3 PLANTS

Vegetation is a highly visible, key component of wetlands. The definition given by Glen et al. (1999) for 'aquatic plants' applies to plants growing in the various types of wetlands listed in the Ramsar Convention:

'An aquatic plant is a plant belonging to either the Charophyta, Bryophyta, Pteridaphyta or Spermaptophyta of which the photosynthetically active parts are permanently or at least for several months of each year submerged or float on the surface of the water. These plants are entirely dependent on the presence of water, are adapted in various forms to live in this environment, and are unable to complete their reproductive life cycle unless they have this close association with water for at least part of their life cycle'.

Wetland plants are termed 'hydrophytes' and are further divided into submerged hydrophytes, which have all photosynthetic parts submerged, and emergent hydrophytes, in which some photosynthetic parts are in contact with air. Those plants which grow in wetlands but are not dependent on being submerged for part of their life cycle (but can tolerate submergence) are termed 'helophytes', or 'semi-aquatic plants'. Hydrophyte species have physiological, morphological and reproductive adaptations which enable them to grow, reproduce and persist in a range of soil conditions (from saturated to dry; DWAF 2003). Obligate hydrophytes are only found in wetland environments, while facultative hydrophytes occur both in wetland and non-wetland environments (DWAF 2003).

Wetland plants, being sensitive to hydrology, are commonly used to delineate wetland boundaries (DWAF 2003, Adamus et al. 2001). The interest, for this application, is in what dominant *groups* of hydrophilic plant species are present, rather than on what individual indicator species occur. Where only a few wetland plants occur in an area dominated by terrestrial plants, it cannot be inferred that the area is a wetland (DWAF 2003). Characteristic vegetation species occur in each of the three zones of a wetland (permanent, seasonal and temporary) used for the purposes of wetland delineation and assessment.

The location of wetland plant community zones and their species composition are influenced largely by factors such as water regime and salinity, with the next most important factor (within a given hydrological regime) likely to be anthropogenic disturbance (DeKeyser et al. 2003).

According to US EPA (2001b, citing Wiegleb 1988; Mitsch & Gosselink 2000), the following vital contributions are made by plants to wetland ecosystems:

- 'Wetland vegetation is at the base of the food chain and, as such, is a primary pathway for energy flow in the system. Through the photosynthetic process, plants link the inorganic environment with the biotic one. Primary production (or plant biomass production) in wetlands varies, but some herbaceous wetlands have extremely high levels of productivity, rivaling those of tropical rain forests.
- Wetland vegetation provides critical habitat structure for other taxonomic groups, such as epiphytic bacteria, phytoplankton, and some species of algae, periphyton, macroinvertebrates, amphibians, and fish. The composition and diversity of the plant community influences diversity in these other taxonomic groups.
- Strong links exist between vegetation and wetland water chemistry. Plants remove nutrients through uptake and accumulation in tissues, but they also act as a nutrient pump by moving compounds from the sediment and into the water column. The ability of vegetation to improve water quality through the uptake of nutrients, metals, and other contaminants is well documented

- Vegetation influences the hydrology and sediment regime through processes such as sediment and shoreline stabilisation, or by modifying currents and helping to desynchronise flood peaks.'

Changes to water quantity and quality, and to species composition through invasions and habitat change are the major agents of change for wetland plantsm and can threaten the long-term survival of wetland plant communities. Plants inevitably respond to alterations of structural, temporal, spatial and biotic attributes of wetland habitats and wetland systems across the landscape by moving location, tolerating change or changing growth form or life cycle stage, or disappearing altogether (Brock 2003).

The literature reviewed thusfar suggests that plants are one of the best-understood components of wetland biota, particularly in terms of their relationship to soil types and hydrology (e.g. Reid & Brooks 1998). In South Africa, wetland plants are used by wetland specialists as indicators of wetland condition, when delineating wetlands (DWAF 2003). Although there is as yet no published guide to the wetland plants of South Africa, there are a number of instances in which plant species common to wetlands in particular regions are listed and illustrated, for example: *Water plants of Natal* (Musil 1973); *Aquatic plants of South Africa* (Glen et al. 1999 in Cowan 1999); and *'Field procedure for the identification and delineation of wetlands and riparian areas*' (DWAF 2003). Glen et al. (1999) provided the first list of aquatic plants of South Africa to be published in this country (in Cowan 1999), and discussed the compilation of a key for the different taxa of aquatic plants. In this list, wetland plants are listed in five different categories, each representing particular aquatic habitats (open waters; seepage areas; swamps, marshes and vleis; seasonal pans and streams; and high altitude bogs and mountain rock pools).

6.3.1 Plants as indicators of wetland condition

Wetland macrophytes are regarded as one of the best indicators of the factors that shape wetlands within a landscape (Bedford 1996). Some of the reasons that plants make excellent indicators of wetland condition include their relatively high levels of species richness, rapid growth rates, and direct response to environmental change (US EPA 2001b). They are widely supported as indicators of condition, and are considered particularly useful for this purpose as they can be used to represent both structural and functional elements of ecological character (Butcher 2003). From a functional perspective, plants are involved in energy flow and nutrient cycling. Structural aspects such as plant species composition may be affected by impacts such as nutrient enrichment and eutrophication (Butcher 2003). Vegetation has also been shown to be a sensitive measure of human-induced changes in wetland ecosystems. Individual plant species show different sensitivities to a wide array of stressors. As environmental conditions vary, community composition shifts in response.

US EPA (2001b) lists a suite of references which illustrate the relationship between change in wetland plant community composition and a number of key stressors: hydrologic alterations, nutrient enrichment, sediment loading, turbidity, and metals and other pollutants. The water regime is considered a driving variable with respect to the structure (e.g. species richness) and function (e.g. primary production) of the plant community.

Key variables within the water regime that affect wetland plants include water depth, water chemistry and flow rate (US EPA 2001b). Linked variables include connectivity to suitable habitats, and competition between plant species (Adamus et al. 2001, Butcher 2003). These are variables which are all affected by natural dynamics (including successional change in composition), as well as human disturbance, so that the cause-effect relationship may not be easy to establish. Even under natural conditions, in a wetland with high hydrological variability, the plant community Is not stable over time (Butche 2003). Natural disturbances can also result in changes in species composition which endure over the short or longer term. For these reasons, Wilcox et al. (2002) suggest that plant indices may be best suited to those wetlands which have a stable hydrology (i.e. which are not exposed to natural disturbances).

In certain situations, however, a plant index is the most obvious choice. For instance, in seasonal wetlands which dry out at times, rendering them highly susceptible to human disturbance, there is no guarantee that there will be sufficient surface water to allow efficient sampling of macroinvertebrate and phytoplankton. DeKeyser et al. (2003) conclude that in such systems, the only logical biota to sample are plants.

While plants are probably the most widely-supported biota for assessing wetland condition, there are also a number of limitations which need to be addressed. For instance, Butcher (2003) reports from Victoria (Australia) that the number of trained plant ecologists in agencies who have skills in wetland plant taxonomy is a far smaller than the number of trained macroinvertebrate taxonomists. This situation is likely to be similar in South Africa, where the use of vegetation as a primary indicator of wetland condition (in delineation) requires expert knowledge (DWAF 2003). There are few trained wetland plant taxonomists in South Africa. If such a method were to be developed for use in this country, it would be necessary to build capacity through training courses.

For the purposes of Ecological Reserve Determination, where it is important to understand the link between biota and hydrology, further research on the relationship between environmental conditions (particulary hydrology) and the response of different plant species and communities would be advised. This would assist in better facilitating the detection of impairment (e.g. US EPA 2001b).

Sampling techniques would also need to be refined and further developed for certain circumstances, such as for wetlands which occur in a mosaic of wetland patches interspersed with another habitat type. Other concerns in selecting sampling methods, as reported by Ohio EPA (Mack and Fennessy 2001), are the ease of use, cost, and repeatability of results, and the gathering of as comprehensive a list of plant species as possible. To address the last of these, the agency developed the Floristic Quality Assessment Index (FQAI), which requires a relatively complete list of flora of a site.

A number of advantages, disadvantages, and limitations of using plants (and specific plant groups) as indicators of wetland condition are listed in Text Boxes 6.1- 6.2. If the limitations of using wetland vegetation as an indicator could be addressed, wetland vegetation promises to be one of the best indicators for use in assessing the biological integrity of wetlands.

Text Box 6.1 Advantages and limitations of using vegetation in biological assessment. From *USEPA (2001b, references cited are excluded)*

ADVANTAGES

- Plants are found in all wetlands.
- Plants are primarily immobile (save for a few free-floating species). Because they reflect the temporal, spatial, chemical, physical, and biological dynamics of a system, they can indicate any long-term, chronic stress it undergoes.
- Plant taxonomy is well known, and excellent field guides are available for all regions.
- Experienced field biologists can identify genus or species relatively easily because:
    - A great diversity of species exists with differing responses to human disturbance.
    - Ecological tolerances are known for many species, and thus changes in community composition might be used to diagnose the stressor responsible. For example, plant responses to changing hydrology are reasonably predictable.
    - Sampling techniques are well developed and extensively documented.
    - Similar sampling techniques can be used in both freshwater and saltwater systems.
    - Functionally or structurally based vegetation guilds have been proposed for some regions.

LIMITATIONS

- A lag may occur in the response time to stressors, particularly in long-lived species. When this is the case the species present may not be indicative of the stressors present and/ or the overall biological integrity.
- Plant identification to species level can be laborious, or restricted to narrow periods during the field season. Several assemblages, such as the grasses and sedges, may be particularly difficult to identify to species. Concern is sometimes expressed about the skill that good field botany requires. However, with a modest amount of training, most species in a given class of wetland can be easily learned, or the art of keying out species can be learned
- Sampling techniques for some assemblages, such as the submerged species, can be difficult; thus it is possible to miss or erroneously sample a group of species that could provide strong signals on the condition of a site.
- Vegetation sampling is generally limited to the growing season.
- Research or literature on plant species responses to specific stressors is not well developed.

Text Box 6.2 Advantages and disadvantages to the use of different vegetation types in biological assessment. From *Butcher (2003, adapted from Adamus & Brandt 1990 , USEPA 1998, and personal observation)*

Submerged Aquatic Vascular Plants

ADVANTAGES

- Extremely sensitive to turbidity, eutrophication, hydroperiod, herbicides, metals;
- Sensitivities of several indicator species are well known;
- Relatively important in food webs (e.g. Waterfowl);
- Immobile and thus reflective of site conditions;
- Structural component; littoral habitat for fauna;
- Sampling is relatively easy; simple abundance metric;
- Integrators of environmental conditions;
- Patterns interpretable using remote-sensing.

DISADVANTAGES

- Some difficult to sample systematically throughout a wetland;
- Absent from wetlands that lack standing water (e.g. Bogs);
- Tolerant of intermittent pollution;
- Laborious identification;
- Low social recognition of their importance;
- Few if any regional field databases exist.

Non-rooted Aquatic Vascular Plants

ADVANTAGES

- Extremely sensitive to nutrient additions;
- Sensitivities of some indicator species (eg, *lemna*) are well known;
- Important in food webs (e.g. waterfowl);
- Mostly immobile and thus reflective of site conditions;
- Patterns sometimes interpretable using remote sensing.

DISADVANTAGES

- Difficult to sample systematically throughout a wetland;
- Limited bioaccumulation due to short lifespan;
- Absent from wetlands that lack standing water (e.g. bogs);
- Laborious identification;
- Low social recognition of their importance;
- Few if any regional field databases exist.

Emergent (Herbaceous) Vascular Plants

ADVANTAGES

- Occur in virtually all wetlands;
- Sensitivities of some indicator species (eg, *Typha,Phragmites, Phalaris*) to nutrients/sediment are well known;
- Immobile and thus reflective of site conditions, useful for *in situ* exposure Assessments;
- Bioaccumulate to a moderate degree;
- Patterns interpretable using remote sensing;
- Moderately sensitive to nutrients and hydroperiod alteration;
- Some regional field databases may exist.

Disadvantages

- Not highly sensitive to contaminants and sedimentation;
- Lagged response to stressors (episodic contamination may not be reflected);
- Low social recognition of importance;
- Sampling and identification is laborious;
- Dispersal, herbivory, soil type and other factors often overshadow contaminant effects.

Text Box 6.2 *Cont.*

Forested/Shrub (Woody) Vascular Plants

ADVANTAGES

- Occur widely;
- Sensitivities of many species to hydroperiod change are relatively well known;
- Immobile and thus reflective of site conditions;
- Bioaccumulate to a moderate degree;
- Patterns interpretable using remote sensing;
- Sampling techniques and community metrics well-developed;
- Trends can be inferred (with care) using tree ring analyses;
- Signs of stress (e.g. Die-offs) are socially recognized;
- Sampling and identification are fairly easy;
- Community can be characterised even in the dormant season.

DISADVANTAGES

- Not highly reflective of contaminants and sedimentation;
- Long lagged response to stressors (episodic contamination may not be reflected); *in situ* experimentation is impractical;
- Response difficult to interpret where past management (e.g. Silviculture) has been practised.

6.3.2 Wetland assessment methods using plants

A number of attempts at developing plant indices for the purpose of assessing wetland condition are reported in the US (e.g. Adamus et al. 2001). Three of these are described here.

Index of Plant Community Integrity (IPCI)

(DeKeyser , Kirby & Ell 2003)

The Index of Plant Community Integrity (IPCI) was developed for quantitative assessment of temporary and seasonal wetlands of North Dakota, which represent 43% of the total acreage of water in the state. One of the aims of the research was to test whether the IPCI could be incorporated into the Hydrogeomorphic Classification Model (HGM) of Brinson (1993).

The development of the method was conducted in the Prairie Pothole Region (PPR). Forty six seasonal wetlands, representing a wide range of disturbances from least-impacted to degraded, were sampled for their plant communities during 1998 and 1999, using a quadrant method. Nine metrics were chosen for use in the assessment, each showing a distinct linear change over the disturbance gradient. The metrics included:

- the **'Percentage of annual, biennial and introduced species'** metric which uses information on the 'C-value' (a coefficient of conservatism of a native plant species, providing a measure of how intolerant an indigenous plant species is to disturbance, with values ranging from 0-10), and
- a **Floristic Quality Index or FQI** (the average 'C value' multiplied by the square root the total number of plant species listed for an area).

The nine metrics were calculated for each individual wetland on the basis of the species list from the survey. The metric data were standardised, and the standardised data were analysed using Principal Components Analysis (PCA). Significance of principal components was established. A cluster analysis procedure was then performed on the significant axes generated in PCA, to establish groupings of wetlands. The groups formed were visually differentiated using a dendrogram. Quality classes (disturbance groups) were categorised by subjectively setting the cluster distance of the dendrogram. These groupings were tested to see if they were significantly different. Once significantly different groups had been found, they were examined for the similarity of species found at each wetland within the group, and the similarity of metric values at each wetland in the cluster. Based on the final groupings, three value ranges were determined for each of the nine metrics (to follow Karr's 1981 multimetric approach).

Three value ranges were determined for each metric, and then assigned a 5,3 or 1:

5 if the values were similar to the values of wetlands in the Very good and Good cluster groups

3 if the values in that range matched the values of wetlands in the Fair cluster group

1 if the values closely matched the metric values of wetlands in the Poor group.

These values were then added together to get a total metric score for the wetland. Total metric scores indicated the quality of the plant community in each wetland and were related to the degree of disturbance impacting the wetland (the score decreases as disturbance intensity increases). The wetland plant communities were separated into 5 quality classes which were determined to be statistically different: 1(Fair), 2(Good), 3 (Very good), 4 (Poor) and 5 (Very poor). Wetlands in the PPR can be assessed using IPCI and placed in these quality classes for mitigation and ecological purposes.

This approach to incorporation of a biotic index into the HGM approach is of relevance to the South African situation. It may be possible to consider the development, incorporation and testing of one or more biological indices into the new functional index, WETLAND-ASSESS, of Kotze et al. (2004).

Index of Vegetative Integrity (IVI) using Plants

(Gernes in US EPA 2002b, Gernes & Helgen 2002)

This multimetric index has been used effectively in Minnesota to assess wetland condition. Minnesota has proposed 10 wetland vegetation metrics that have been combined into the index. Two metrics focus on taxa richness, four are based on life-form guilds, two are sensitive and tolerant taxa metrics, and two are community-structure metrics.

The ten metrics are:

- **Vascular genera:** expresses the richness of native genera occurring in the wetland, (i.e. the number of native vascular plant genera in a 100 m^2 releve plot).
- **Nonvascular taxa:** expresses the number of nonvascular taxa including liverworts, mosses, lichen taxa, and the macroscopic algae *Chara* and *Nitella.*
- ***Carex* cover:** this metric was calculated by summing the cover class for all *Carex* taxa sampled in each plot.
- **Grasslike species:** The grasslike species metric expresses the richness of grasses (Poaceae), sedges (Cyperaceae), and rushes (Juncaceae).
- **Monocarpic species metric:** This metric is calculated as a sum of the monocarpic species richness and cover class values divided by the monocarpic species cover.
- **Aquatic guild:** evaluates the number of aquatic guilds at a site. Submerged plants, either rooted or unrooted, and floating vascular plants such as the duckweeds are life-form-dependent aquatic macrophytes that comprise the aquatic guild used in this metric.
- **Sensitive taxa:** evaluates the decrease in richness of taxa that are most susceptible to human disturbance.
- **Monocarpic species:** the sum of the monocarpic species richness and cover class values divided by the monocarpic species cover.
- **Dominance metric:** incorporates the distribution or concentration of cover class values relative to the taxa richness for native species within the sample.
- **Persistent litter:** Persistent litter is defined as being resistant to decomposition. Scoring for the persistent litter metric was based on a sum of the abundance cover classes for

plant taxa recognized as having persistent litter.(including *Phragmites,* bullrushes *Scirpus, Polygonum*, and *Typha.*

All sampling was conducted in the wetland emergent vegetation zone. Reference sites were chosen as least-impacted wetlands; stormwater runoff or agricultural activities disturbed the other sites. Scoring criteria for the nine metrics described are shown in Table 6.1.

Table 6. 2 Scoring criteria for vegetation-based metrics in the Minnesota IVI. The number of sites scoring at each level is given, as the number of least-impacted reference (ref) sites.

Vascular plant metric			**Aquatic guild metric**		
Genera	Score	#Sites	Species	Score	#Sites
>14	5	6 (3 ref)	> 6	5	5 (4 ref)
.9-14	3	10 (3 ref)	.3-6	3	9 (2 ref)
< 9	1	10	< 3	1	12
Nonvascular plant metric			**Sensitive taxa metric**		
#Taxa	Score	#Sites	Sensitive species	Score	#Sites
>1	5	6 (4 ref)	> 4	5	3 (ref)
1	3	7 (2 ref)	.1-3	3	12 (3 ref)
0	1	11	0	1	9
Carex cover metric			**Tolerant taxa metric**		
Total Carex Cove	Score	#Sites	Tolerant Taxa	Score	#Sites
> 3	5	6 (2 ref)	< 25%	5	4 (4 ref)
0.1 - 2.9	3	11 (4 ref)	25.1 - 60%	3	12 (2 ref)
0	1	9	> 60%	1	10
Grasslike species metric			**Dominance metric**		
#Species	Score	#Sites	Dominance	Score	#Sites
> 8	5	4(2 ref)	< 0.07	5	7 (3 ref)
7-Feb	3	6(4 ref)	0.08 - 0.2	3	11 (3 ref)
< 2	1	12	> 0.2	1	8
Monocarpic species metric			**Persistent litter metric**		
Cover	Score	#Sites	Cover	Score	#Sites
> 2.5	5	7 (4 ref)	< 25%	5	6 (4 ref)
2.0 - 2.49	3	11 (2 ref)	25 - 75%	3	13 (2 ref)
< 2.0	1	8	> 75%	1	7

Note: All data were collected in 100 m^2 releve plots.

Multimetric indices of biotic integrity for riverine and palustrine wetland plant communities along Southern Lake Michigan

(Simon et al. 2001)

This is a rapid, plant-based multimetric plant index of biotic integrity (PIBI), developed for use in palustrine or riverine wetlands along Southern Lake Michigan. In development of the method, 18 riverine wetland sites and 10 palustrine wetland types were sampled along Southern Lake Michigan. Sites ranged in condition from least to most impacted.

The authors reviewed both literature on aquatic plant assemblage structure and function, and on life history and tolerance information for species from the two sampling areas. Over 20 attributes of aquatic plant communities were evaluated, and 12 metrics in five categories were developed and incorporated into separate indices for palustrine and riverine wetlands. Structural metrics focussed on community composition, key indicator species and guild types. Functional metrics included sensitivity and tolerance measures; percent emergent, pioneer and obligate wetland species and the number of weed species as a substitute metric. Ratings were used to classify aquatic plants based on national wetland rankings of facultative (FAC), facultative wetland (FACW) or obligate wetland (OBL).

Sampling was done by surveying each site up to 100m distance in the near shore, off shore and littoral zone of palustrine wetlands and within the floodplain and stream channel of riverine wetlands where obligate and facultative wetland species would be anticipated. The sampling intent was to perform a representative qualitative survey, not an exhaustive census, and was targeted at biological diversity and relative abundance estimates. All species were identified and an abundance rating (1- Observed, 2- Rare, 3-Rare/Common, 4-Common, 5- Very common, 6- Abundant) was assigned to each. Identifications were done in the field and the unknowns were identified using appropriate floristic manuals.

PIBI was calculated for the 28 sites assessed. The authors modified Karr’s (1981) description IBI class scoring attributes for fish to reflect those appropriate for aquatic plant assemblages. The scoring has three levels: ‘5’ as representative of the reference condition, ‘3’ to show deviation from the reference condition, and ‘1’ where the metric value is significantly different from that of the reference condition. For each metric, a range of values is attached to each of these three condition classes. The PIBI provided scores comparable with other indicators of biological health and was able to discriminate between riverine and palustrine sites. Sites that received highest scores were the least affected by anthropogenic disturbances.

Plant IBIs in Ohio

(Mack 2001)

Based on the results of extensive sampling method development and research into developing biocriteria and IBIs for wetlands during the late 1990s, the Ohio EPA supports the use of vascular plants as a taxonomic group for development of wetland biocriteria. Successful metrics for emergent wetlands include:

- Floristic Quality Assessment Index (FQAI)
- Ratio of Shrub Species to Total Species
- Number of *Carex* spp.
- Number of Dicotyledonous. spp.
- Numbers of plants with facultative wet (FACW) or obligate wet (OBL) wetland indicator status
- Heterogeneity (Simpson’s Index)
- Standing Biomass
- Relative cover of tolerant and intolerant plant species (where tolerance is determined by the plant’s coefficient of conservatism, which is derived from a State or regional FQAI system).

For wetlands dominated by woody species, relative density of shrubs and small trees and tree size classes have also been shown to be useful metrics. Ohio EPA found the FQAI scores and subscores to be very successful attributes and metrics for detecting disturbance in wetlands (Mack 2001).

The sampling method finally adopted by Ohio EPA after experimentation with various options in the late 1990s, is a plot-based method which allows for qualitative stratification of the wetland by dominant vegetation communities. A set of ten 10x10m sampling units are used within a 20x50m grid, which is located such that the long axis of the plot is oriented to minimize the environmental heterogeneity in the plot. Within the sampling units, standard quantitative floristic and forstery information is recorded, e.g. density, basal area, cover, etc. The method is reportedly flexible and adaptable to unique site conditions, provides dominance data for all plant species in all strata, provides data which can be compared to other common methods, is relatively easy to learn, and is relatively fast and cost-effective.

Mack (2001) comments on the importance of collecting dominance and density information (cover, basal area of trees, stems per unit area, relative cover, relative density, impotance values, etc.), as many of the most successful attributes used in the Ohio EPA are based on cover data of the herb and shrub layers, and density data of the shrub and tree layers.

Determining tolerance groups of wetland plants for use in a Plant-Based IBI

(Wardrop & Brooks 2001)

These authors describe the process by which individual plant community metrics have been tested for robustness along a gradient of human disturbance in Pennsylvania wetlands, in preparation for a plant-based IBI for wetlands.

The authors examined the range of human disturbances in the area, and found the key disturbances to be hydrologic modification, sedimentation, and nutrient input. They looked at the weak correlations between these and the general measures of plant community response (e.g. species richness, diversity and evenness). It was decided that more suitable, stressor-specific metrics should be developed for this purpose. As the functional (or tolerance) groups available did not include traits which indicated a plant's ability to tolerate sedimentation, tolerance groups of plants relating to sedimentation and hydrologic stress were constructed on the basis of field data from 70 wetland sites. These were chosen to encompass six common HGM classes of the State's five ecoregions, as well as high, moderate and low levels of human impact. Species were categorised in a range of tolerance groups, from intolerant to very tolerant.

The authors report that characterization of plant communities in these wetlands showed a clear association between individual species and their ability to tolerate sedimentation (this is also dependent on other co-occurring stresses, e.g. wetting and drying cycles). Sediment tolerance groups were established for each HGM wetland type. The usefulness of a plant species as an ecological indicator of sedimentation was established by assessing validity (how often it occurred in association with a particular sedimentation category) and significance (the frequency of association relative to the indicator species' occurrence in the absence of the sedimentation).

Hydrologic groups were established along similar lines using well data collected on 6 hourly water level at 27 wetland sites. Hydrologic measures were: median depth to water, percent time water level was within the top 30cm, percent time upper 30cm was saturated, inundated, or dry, percent time upper 10cm was saturated, inundated or dry. Sites were assigned to one of five hydrologic groups (predominantly-inundated to predominantly-dry), using plant data from 406 plots (187 plant species) to construct the groups. This was done by tabulating average percent cover of individual species presence within each of the five groups. Wardrop and Brooks (2001) found that wetland plant indicator status (obligate, facultative etc.) was a poor indicator of an individual species' hydrologic regime. However they report that HGM classification is an acceptable surrogate.

The authors suggest that the approach of developing stressor-specific tolerance groups of plant species on the basis of field data is an effective means of developing metrics for a plant-based IBI for the following reasons: there are then well-established and documented links of each species to specific stressors; ecological suitability of a site for individual plant species is documented; field-based groups compliment literature-based ones; and field-based metric construction improves the diagnostic capability of metrics.

6.3.3 ALGAE / DIATOMS

Algae are an important constituent of wetland ecosystems, playing an essential role in nutrient and energy cycling, providing habitat for other wetland organisms, and providing a food source for invertebrates and small fish. Algae are often more important than vascular plants as a source of energy for invertebrates and higher trophic levels (Adamus et al. 2001). Structurally, algae stabilise the substrate and create mats that form habitat for fish and invertebrates. Some invertebrates use algae to construct cases (Bott, 1996).

The US EPA (2002c) groups algae into two major groups: phytoplankton (unicellular and colonial forms suspended in water column), and periphyton (mats of algae). Periphyton is further divided into epidendron (mats or films growing on dead wood), epilithon (mats or films attached to hard surfaces), epipelon (mats, flocs or films attached to hard surfaces), epiphyton (mats or films attached to submerged macrophyte stems and leaves), and metaphyton (mats or filmanets floating on the water surface or suspended in the water column).

Phytoplankton can occur in abundance in deeper and larger wetlands, encouraged by high nutrient levels, low flushing rates, and low grazing pressure by planktivores (US EPA 2002c). Algae strongly influence oxygen levels in the water column through photosynthesis and respiration, and often account for a significant portion of the wetland metabolism (e.g. Maine DEP 2004).

In wetlands, the density and species composition of algal communities often varies over the spatial scale of a few metres horizontally and a few centimetres vertically. Species composition also tends to shift over the temporal scale of seasons and years, although the latter changes may be reasonably predictable, e.g. diatoms are often more common in spring and summer, green algae in summer, and blue-green algae in late summer (Adamus et al. 2001).

Spatial and temporal factors aside, algal community composition in a wetland is largely determined by the physico-chemical features of the system, with water chemistry being more important than hydrology in determining periphyton structure and function (Butcher 2003). As a result of this, the algal community may not match with wetland hydrogeomorphic classification schemes (US EPA 2002c).

6.3.4 Algae / diatoms as an indicator of wetland condition

Algae are among the most widely used indicators of water quality and biological integrity in aquatic ecosystems. More than any other assemblages, they have been used to indicate physicochemical conditions and biotic integrity at a site (US EPA 2002c). They are highly sensitive to a range of environmental stressors, including nutrient enrichment, changes in pH, conductivity, sediments, organic contaminants, pesticides and many other contaminants (US EPA 2002c, Adamus et al. 1999, Maine DEP).

Since algae have rapid growth rates and respond quickly to perturbations, they often provide an early warning of changing environmental conditions which may not be detected by other methods (Maine DEP 2004). Although species-level assessments yield the most accurate information of environmental conditions and biological integrity, these require the greatest level of taxonomic expertise, and a great deal of information can be acquired from assessments at the level of genus or higher (US EPA 2002c).

Taxonomic analyses often focus on diatoms (unicellular, autotrophic algae) within the assemblage, as the taxonomy and species autecology of this group is relatively well established and can be readily determined from field collections without extensive additional effort such as culturing (US EPA 2002c). Diatoms are particularly useful in assessing wetlands during dry periods, and to determine historic environmental conditions, as their siliceous cell walls or ‘frustules’ persist in wetland sediments over long periods of time (de la Rey et al. in press, Maine DEP 2004). Diatoms are also useful indicators of changes in salinity, pH and nutrients, and respond rapidly to changing conditions (Butcher 2003, Fore and Grafe 2002).

In South Africa, significant resources have already been invested in the study of diatoms as indicators of wetland condition, by researchers at the University of Potchefstroom (Vosloo pers.comm. 2004). One of the focus areas of this research team is on the development of an diatom index for use in assessing aquatic ecosystem condition. These unicellular organisms can provide a wealth of information regarding the present and historic hydrology and condition of wetlands, and have been shown to be highly sensitive to wetland water quality (in particular levels of Dissolved Oxygen, EC, and metals). The index would be broadly applicable, in that diatoms can be sampled in depths of only 2mm. Sampling techniques in the field are rapid: three stems from the dominant macrophytes in the wetland are cut, diatoms are scraped off these and returned in bottles to the laboratory. Laboratory-processing involves a fairly simple procedure of acid washing, followed by slide-mounting the diatoms. Three slides (A,B and C samples) are created from each sample. One is used for analysis, while the other two can be stored for a number of years. This feature ensures that the method is legally defensible (Vosloo pers.comm.2004).

Although identification of diatoms has been widely thought to be highly complex and difficult to learn, Vosloo (pers.comm. 2004) argues that it is relatively quick to train individuals in diatom identification at genus level. Butcher (2003) corroborates this. Vosloo (pers.comm. 2004) also refers to a computer-based character-recognition model (artificial intelligence system) for diatoms, which is in use in the US. High levels of accuracy in diatom identification have apparently been reported. This technology is however extremely costly.

The potential disadvantage of the diatom index in terms of its use in Reserve Determination methods, is that little is known of the relationship between diatoms and the water regime (Vosloo, pers.comm. 2003). Nonetheless, the method would provide the ecological condition measures for which biota are classically used (PES, EIS, EC) within the Reserve method.

Algal attributes are generally classified as either structural or functional. Structural attributes are based on measurements of biomass, nutrient content, and taxonomic composition of the sample. Functional attributes are based on measurements of growth and metabolic rates (the latter including photosynthesis, respiration, nutrient uptake, and enzyme activity).

Although all attributes of algal assemblages could be used to assess biological integrity, species composition and autecology (environmental preferences of individual species) are considered particularly effective indicators for diagnosing cause of wetland degradation (US EPA 2002c). Other metrics listed by the US EPA (2002c) include taxonomic composition, diversity (taxa richness and evenness), biomass (which exhibits a strong relationship with nutrient enrichment, and is one of the most widely used indicators of eutrophication in aquatic ecosystems), chemical composition (to assess trophic status; contamination of food webs by toxic compounds; and particularly nutrient status, as algae integrate variations in nutrient bioavailability over periods of weeks); growth (algal net production is positively correlated with nutrient net production), metabolism (e.g. photosynthesis, respiration, net primary productivity, and nutrient uptake are all sensitive to environmental change).

The arguments put forward against the use of algae and diatoms in wetland bioassessment are similar to those for macroinvertebrates: that they are difficult to sample in wetlands, they vary widely over spatial and temporal scales; they require specialist taxonomists to identify them; and the assessment processes used will, in the end, be costly (Butcher 2003, US EPA 2002c). However, the literature and discussions with algal specialists (e.g. Joska pers.comm. 2004) suggests that algal taxonomy can be fairly easily taught (requiring a similar level of effort to teaching plant or macroinvertebrate taxonomy), that the publication of simple pictorial identification guides would assist the identification process greatly, and that examination of functional aspects of algae require laboratory skills rather than taxonomic skills (Butcher 2003, US EPA 2002c). There seem to be as many arguments pro- the use of algae as an indicator as against it.

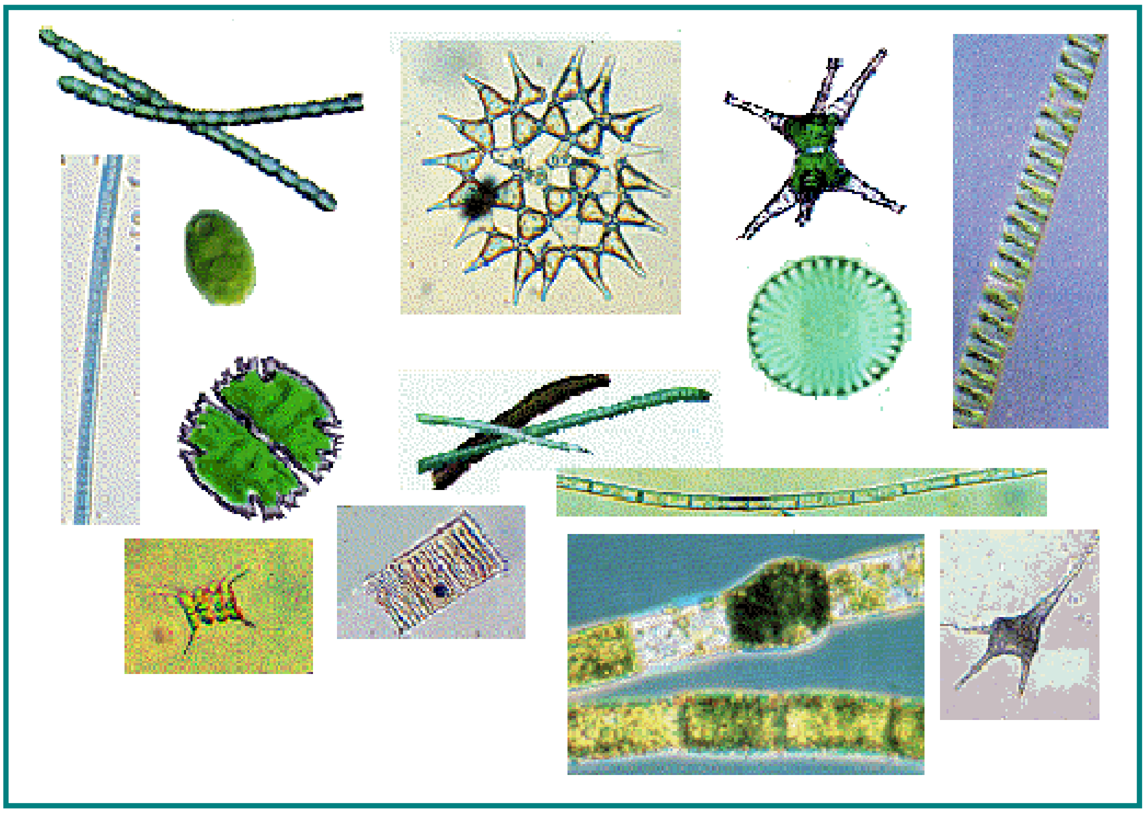


Plate 6.1. Phytoplankton

Some of the advantages and disadvantages of using algae in wetland bioassessment are listed in Text Box 6.3.

Text Box 6.3 Advantages and disadvantages of using algae as indicators of wetland condition. *From Butcher (2003, citing Adamus & Brandt 1990, US EPA 1998 and personal observation) and US EPA (2002c).*

ADVANTAGES

Algae:

- Provide an integrated picture of wetland condition;
- Provide a tight linkage to fundamental processes (e.g. photosynthesis, respiration);
- Have pivotal relationships in food webs;
- Are simple biomass indicators;
- Have tolerances and provide indicator value that are relatively well-known (this applies particularly to nutrients, and most algae are very sensitive to herbicides, and respond well to water quality variables such as nutrients, pH, alkalinity, metals and temperature);
- Usually respond immediately to stressors;
- Have rapid growth rates, allowing for experiemental manipulation to determine cause-effect relationships between algal response and specific stressors;
- Are generally immobile and thus reflective of site conditions, useful for *in situ* exposure assessments and whole-effluent bioassays.

In general:

- Field sampling and laboratory processing times are equivalent to those required for other indicators;
- Skills in algal taxonomy can be readily developed with an introductory course, experience, a good library of taxonomic literature and consultation with other taxonomists.

For diatoms:

- The glass cell walls of diatoms that accumulate in sediments provide a historic record of ecological conditions;
- The persistence of diatoms in sediments (even when wetlands are dry) may provide a year-round approach for assessing ecological integrity of wetlands.

DISADVANTAGES

Algal:

- Response is often not identifiably stressor-specific;
- Identification can be laborious and requires taxonomic expertise;
- Indices need regional databases;
- Rapid turnover rates requires frequent sampling;
- Importance has low social recognition;
- Bioaccumulation is not measurable;
- Quantitative inference of water quality requires large calibration data set;
- Drifting cells of unattached species complicate interpretation;
- Taxa are mostly relatively insensitive to heavy metals and pesticides.

6.3.5 Wetland assessment methods using algae

Numerous studies have been conducted using algal assemblages specifically to indicate the condition of a large series of wetlands. In the US, these include studies in Montana, the Midwest, and south-western Maine. Adamus et al. (2001) cite a number of references to information regarding algal tolerance ranges to a number of anthropogenic disturbances, and the use of algae to develop biocriteria for wetland assessment.

In the US, the Department of Environmental Protection, Maine, is working to develop biological indicators based on wetland algae (Maine DEP 2004). Models using algae to predict Total Phosporus and conductivity were developed and tested in the US by Pan and Stevenson (1996, cited by Adamus et al. 2001). Their finding was that the model which used planktonic algae was superior for predicting conductivity, whereas the model using epiphytic diatoms was superior at predicting Total P.

Joska (pers.comm. 2004), a South African specialist in freshwater algae, comments that different genera of algae are excellent indicators of various water quality parameters, (including conductivity, nutrient enrichment and contamination). She reflects that there are, however, few trained algal taxonomists in SA who would be in a position to use an index of condition based on algae. Such a method would also not be rapid and field-based, but would require laboratory identification (using a compound microscope) within a few days of sampling. Joska recommends using algae as a broad descriptor variable in the field, to augment and verify the information acquired from other bioindicators. Adequate training could be achieved within a day to achieve this level of expertise. Joska reports that if a photographic guide to freshwater algae (similar to that produced in Australia) were to be commissioned, this would facilitate relatively easy field identification of algae for trained individuals. This would add resolution to a field-based exercise.

Butcher (2003) reports that in Tasmania, two wetlands have been listed as high value sites on the basis of the community structure of the algae present. She also cites cases of regional NRE groups using diatoms successfully in salinity monitoring, rather than macroinvertebrates. Butcher (2003) concludes in her review that the value of diatoms as an index in widespread monitoring and assessment of wetlands may not have been sufficiently tested.

Development of algal indicators of the ecological integrity of Maine wetlands
(DiFranco and Stevenson 2002)

The Maine Department of Environmental Protection (DEP) initiated a Casco Bay watershed assessment in 1998, with the objective of developing sampling methods for algae and macroinvertebrates; developing biological criteria for Maine wetlands; and diagnosing stressors degrading wetlands. Twenty wetlands were selected in the watershed. All wetlands were semi-permanent or permanent depressional wetlands and were selected on the basis of six criteria: hydrologic regime, distribution of sites, landscape position, disturbance gradient, management significance, and accessibility. Six sites were selected as reference sites and the others represent a range of human disturbance.

Four algal sample types were tested to determine which produced the best indicators of wetland condition.
Water Column - Water samples are collected for quantitative analysis of phytoplankton abundance and species composition. Chlorophyll a was also analysed as an indicator of algal biomass. A long handled dipper was used to collect water samples just below the water surface. Water from multiple areas of the wetland were combined into a single sample.
Plant Stems - Garden shears were used to clip plant stems below the water line to collect epiphytic algae. The plant stems were placed into a whirlpak bag, and distilled water was added. The stems were then massaged to remove attached algae and diatoms, rinsed with additional distilled water and discarded. As of 2002, the surface area of each plant stem was also calculated from field measurements to obtain a more quantitative sample.

Sediments - Sediments for qualitative algae and diatom samples were collected using a basting brush and/or plastic spoon. As of 2002, a quantitative sample was obtained using a petrie dish pressed into the substrate and retrieved with a spatula. Three replicates were collected and combined into a single sample.
Multi-Habitat Sample - Material from each of the above single-habitat samples was combined into a single container to obtain a qualitative multi-habitat sample.

Three disturbance indicators were used to evaluate responses of algal attributes to human wetlands:

- A land-use indicator developed by Maine DEP
- Trophic status indicators (total Nitrogen, total Phosphorus, Chlorophyll a)
- Hydrologic and sewage chemicals (Ca, Na, Cl).

A suite of algal attributes was compared to the disturbance indicators to check which responded. The indicators included:

- Genus and species richness
- Shannon diversity
- Number of taxa in different genera
- Weighted-average autecological indices
- Relative species abundances.

The study reported that diatoms collected from plants, sediments and the water column provided similar numbers of metrics of biological integrity and indices of stressors. However far more diatom assemblage attributes from single habitats were correlated with gradients of human than were those from multi-habitat samples.

Metrics found to correlate best with human disturbance indicators included those based on the the number of taxa in common genera and on autecological characteristics (even though the latter information was sourced from European studies). The indices based on autecological characteristics gave better results than did the genus-based metrics.

In general, algae responded more to direct indicators of individual stressors, such as nutrient enrichment, that to a cumulative summary index of human disturbance based on field assessments. Total P correlated to more algal attributes than did Total N or Chlorophyll a in the water column.

Determining the value of diatoms as indicators of water quality (in SA)

(de la Rey et al. *in press,* Vosloo pers.comm.)

A group of researchers at Potchefstroom University in SA are presently engaged in research regarding the use of diatoms as indicators of broad water quality. Although their published research relates to rivers, the application of the diatom work is relevant to wetlands (Vosloo, pers.comm. 2004). Tests have been done to evaluate the applicability of a European diatom index, the 'Specific Pollution Sensitivity Index' (SPI) in a river system, relative both to chemical water quality results, and those arising from the use of the South African Scoring System 5 (SASS5) index for aquatic invertebrates.

The rationale for this is that diatoms may be able to provide answers to certain of the problems encountered in monitoring rivers for inorganic nutrients, organic loading, ionic composition, and dissolved oxygen (Kwandrans et al. 1998 are cited).

Twelve sampling sites in the Mooi River (North West Province, SA) were selected. Sites were selected to represent a range of water quality and the impact of some of the tributaries entering them. Invertebrates were collected following SASS5 protocols. Diatoms were collected from three to five boulders (in current) at any one site, and returned to the laboratory for processing, slide-mounting and identification. At least 400 frustules (diatom cell walls) were examined for each sample. The SPI index was calculated as prescribed by the European SPI method. Chemical analyses were conducted for Total Nitrogen, Ammonium, Total Phosphate, Chemical Oxygen Demand, Five day Biological Oxygen Demand, Sulphate and Chloride, according to Standard Methods. Additional on-site measurements included temperature, electrical conductivity, dissolved oxygen, and turbidity.

Following statistical analysis, the study indicated that the diatom index was more sensitive to the elevated physical and chemical parameters recorded for the Wasgoed Spruit than was SASS5. Here the SPI displayed a value indicating poor water quality. Water quality results were interpreted to be poorest in this system, with elevated levels of chloride, sulphate, ammonia and other minerals, and the highest electrical conductivity recorded in the system. In the Wonderfontein Spruit, SASS5 scores indicated poorest water quality and chemical tests revealed highest levels of chemical oxygen demand, chloride and Total Nitrogen. The SPI index indicated that the water was of moderate quality. In this case, the SPI scores did not accurately reflect the degree of pollution in this system.

SPI scores were shown to correlate positively with pH, and negatively with electrical conductivity, chloride and ammonium. SASS5 index scores did not show any correlation with water quality variables, however ASPT (average score per taxon) values were positively correlated with the biological oxygen demand and sulphate levels. Multiple regression indicated that sulphate, Total Phospate and Dissolved Oxygen accounted for approximately 74% of the variability in SASS5 index values, and the first two of these variables accounted for approximately 68% of the variability in ASPT values. Approximately 99% of the variation in SPI scores was accounted for by various water quality variables, including Chloride, pH, turbidity, chemical oxygen demand, and Sulphate, indicating index sensitivity to these variables.

97% of the 187 diatom species collected could be used in the SPI index, illustrating their cosmopolitan nature and the potential for (cautious) transferability of the European index.

The authors remark that the different sensitivities displayed by SASS5 and SPI illustrates the reason for using a suite of bioindicators to properly assess the status of an ecosystem. On the basis of their results they conclude that the system has value in providing a reflection of general water quality. On the basis of the strong correlation between SPI and conductivity, they suggest that (for the purposes of river biomonitoring) this index may give a more accurate reflection of the ionic composition of water than does SASS5. They refer to the need for a biological indicator which can be used to monitor water bodies for which SASS5 is not appropriate (where depth and flow are constraints). This hints at their potential usefulness as indicators of water quality state (and potentially more) in wetlands.

Further research into the use of diatoms as indicators of water quality and broader ecosystem status in wetlands is strongly urged, particularly in the light of the positive approach to the use of diatoms for wetland assessment emerging from reviews of the international literature (e.g. Butcher 2003, Adamus et al. 2001). However, it is felt that it would be far more valuable to test the performance of such an index by simply correlating the various diatom attributes (or metrics) with changes in water quality variables and indicators of human disturbance factors, rather than by comparing it to an index such as SASS5. The latter has only ever been marketed as a broad indicator of organic pollution and of macroinvertebrate trends, and cannot provide sufficient information in one sampling (of a small number of sites) to make inferences from.

Further discussion on the potential of algae and diatoms as indicators is provided in the final chapter of this report (Chapter 8).

6.4 AQUATIC MACROINVERTEBRATES

Macroinvertebrates play a vital role in all wetland communities, as an important component in the food web, and by recycling nutrients and contributing to the breakdown of organic matter (e.g. Conservation Commission of Missouri 2004). They are found in abundance in large and small, permanent and seasonal wetlands, and occur in the sediments, in the water column, and on and amongst the submerged and emergent vegetation (e.g. Minnesota PCA 2004). Macroinvertebrates are found in virtually all wetlands, and are an essential component of wetland food webs. They consume algae, detritus, plants and smaller prey organisms, and provide an important food source for fish, waterfowl and other wildlife (Maine Department of Environmental Protection 2004). Macroinvertebrates also play an integral role in nutrient cycling and energy transfer, both within wetland ecosystems and between wetlands and other habitats.

Wetland macroinvertebrates differ from stream macroinvertebrates in their greater tolerance of low dissolved oxygen concentrations, however, they are still sensitive to a variety of physical and chemical factors (US EPA 2002a). Unnaturally high levels of nutrients such as phosphorous, and chemicals such as chloride, have been shown to have negative impacts on the invertebrate community. Unstable hydrology and a lack of invertebrate habitat can also have negative impacts (Minnesota PCA 2004).

Davis et al. (undated), in their study of western Australian wetlands, report that wetland habitats, and particularly plant communities, are important determinants of the composition and richness of invertebrate communities. Invertebrate community composition in wetlands within a particular category in western Victoria, Australia, was shown by Butcher (1999) to change significantly both within a wetland type and between different types, with increased duration of inundation. Butcher (1999) commented that this may suggest that variability lay at the level of the wetland, and that the invertebrate fauna of a single wetland may not necessarily be representative of that wetland type. Further work is required to test this.

These few examples illustrate the complexity of interpreting macroinvertebrate data in wetlands, which as characteristically exhibit high physico-chemical ecosystem variability over both time and space. In South Africa and elsewhere, a great deal of work will be required to determine, for the extensive array of wetland types within a suite of different ecoregions, the nature of the relationship between invertebrate community composition, wetland water regime, and present and precedent chemical, physical and hydrological conditions.

6.4.1 Invertebrates as indicators of wetland health

There are two reported schools of thought regarding the use of invertebrates as indicators of wetland health. The first supports the development of invertebrate bioassessment methods similar to those which have successfully been used in stream and riverine environments for many years (e.g. Davis et al. undated). The second holds that macroinvertebrates are too variable in wetlands, and that only community composition at the level of wetland category type is likely to be useful (Butcher 2003).

The general opinion, however, seems to be that invertebrates have potential as measures of broader wetland condition (e.g. US EPA 2002a, Reid & Brooks 2001, Reid & Brooks 1998), but that more testing of this group is required. The major reasons cited for the use of invertebrates is their capacity to integrate the spectrum of available aquatic wetland habitats and condition (MPCA 2004, Helgen 2002), and that they respond with different levels of sensitivity to the numerous human-induced changes occurring in aquatic ecosystems (US

EPA 2002a). Butcher (2003) and US EPA (2002a) present lists of advantages and disadvantages of using aquatic insects, and aquatic macroinvertebrates respectively, in bioassessment (Text Box 6.4).

Helgen (2002), in her discussion of an invertebrate IBI design, points out that the lack of bioassessment in wetlands due to the preferred use of functional assessments can lead to a dearth of information on the ecological condition and biotic health of the system. She comments that, in the absence of bioassessment, wetland practitioners work under the assumption that if the hydrology and other functions of the wetland were intact, then a healthy biology would follow. However, she notes that even without a net loss of wetland surface area, deterioration of wetland health could occur unnoticed in the absence of a knowledge of biotic state.

Text Box 6.4 Some of the advantages and disadvantages associated with the use of macroinvertebrates and aquatic insects in bioassessment. From *US EPA (2002a, numerous references cited are excluded here); and Butcher (2003: Appendix 2, citing Adamus and Brandt (1999), US EPA (1998g) and personal experience).*

ADVANTAGES

Aquatic macroinvertebrates:

- respond characteristically, and with a range of sensitivities, to the major wetland stressors (hydroperiod, sediment, nutrients, contaminants)and stressor types;
- are in common use in ecological assessments and toxicity testing in different kinds of aquatic ecosystems;
- many complete their life cycles in wetlands
- are exposed directly to physical, chemical, and biological stressors within the wetland;
- are commonly and widely distributed in many types of wetlands, even those lacking surface water;
- are important in wetland food webs;
- have public appeal in volunteer monitoring programs.

Aquatic insects:

- are included in well-developed assessment methods (e.g. Index of Biotic Integrity methods) which ***need further adaptation for wetlands;***
- bioaccumulate to a moderate degree;
- can be caged for whole-effluent bioassays or *in situ* assessments;
- can usually be sampled year-round;
- have representative taxa linked to human welfare (e.g. mosquitoes);
- may present identifiable deformities linked to contaminants.

DISADVANTAGES

In the case of aquatic insects:

- sampling protocols are not fully developed for wetlands;
- taxa are difficult to sample, and their true densities are difficult to determine in wetlands with herbaceous vegetation;
- require laborious identification;
- taxa are not recognised by the public as being of high importance;
- taxa show naturally great micro-spatial variation;
- taxa in wetlands may be strongly tied to sources of colonisers and their dispersal mechanisms;
  community composition can be potentially affected by selective predation (e.g. by fish, waterbirds).

6.4.2 Wetland assessment methods using invertebrates

The literature reviewed for this study indicates that the two countries that have been most pro-active in developing methods for wetland assessment using macroinvertebrates have been the US and Australia (e.g. Butcher 2003, US EPA 2002a, US EPA 1998a-f, Bartoldus 1999).

The US EPA strongly supports the development of invertebrate Indices of Biological Integrity or IBIs for wetlands, with present research and development efforts focused in the states of Minnesota, Ohio, Michigan and Florida. The US EPA-coordinated BAWWG (Biological Assessment of Wetlands Workgroup) has one focus group dedicated to examination of the use of aquatic invertebrates in bioassessment. The role of the group includes the identification of potential metrics and examine topics such as when and how to sample each assemblage (EPA 1998b, see Section 4.2.1).

Of the 40 US wetland assessment techniques reviewed by Bartoldus (1999), only two are primarily directed at an assessment of biological integrity of the wetland: the Index of Biological Integrity (after Karr 1981), and the New England Freshwater Wetlands Invertebrate Biomonitoring Protocol (NEFWIB) of Hicks (1997). Additional methods that have subsequently been developed for use in different states of the US include the Minnesota Pollution Control Agency's Invertebrate IBI for Large Depressional Wetlands (Helgen 2002), and the North Dakota Invertebrate IBI for depressional wetlands in the Prairie Pothole Region (US EPA 1998d, updated January 2003). Several other states are using macroinvertebrates to monitor wetland condition, or are in the process of developing and testing protocols which include invertebrates (US EPA 1998d, Maine DEP 2004). In Australia, the SWAMP (Swan Wetlands Aquatic Macroinvertebrate Pollution Sensitivity) method has been developed by Chessman et al (2002) for use in coastal wetlands. Key features of these protocols are described and examined here.

An Invertebrate IBI for Large Depressional Wetlands

(Minnesota Pollution Control Agency 2004 and Helgen 2002)

This is thus a relatively new tool for monitoring wetland health. Minnesota PCA has been at the forefront of developing sampling protocols and analytical tools for wetlands in the US (MPCA 2004). The rationale for the development of the IBI was that, despite the range of functional wetland assessment techniques available, none of these expressly measured biological communities. As a result, despite years of assessments, there was little available information on the ecological integrity and the condition of biological communities in Minnesota wetlands. The outcome was the development of an IBI for invertebrates (Helgen 2002), in combination with an IBI for plants (Gernes 2002).

The approach to monitoring the condition of wetlands using aquatic invertebrates is accompanied by an IBI for assessing wetland vegetation as an indicator of condition. An additional and new method of scoring the gradient of human disturbance using landscape, hydrological and chemical factors (and generating Human Disturbance scores) is also outlined.

In the invertebrate IBI, appropriate measures of the biological health of wetlands are based on various attributes of invertebrates. These are based on, for example, the loss or absence of species directly sensitive to pollutants, the presence of long-lived species that would be impacted by longer-term disturbances, the presence of predators (and thus prey), and the increase in pollution-tolerant taxa or prey taxa.

In development of the IBIs, 44 wetlands, ranging in condition from least disturbed (reference sites) to most degraded or impaired (to ensure a full range of disturbance), were sampled for invertebrates, vegetation, water and sediment chemistry.

This approach ensured a range of biological data for each metric to derive the metric scoring criteria. To establish the scoring criteria for the individual metrics, the metric data were plotted and related statistically to several measured factors of disturbance to wetlands. The biological data are related to measures of water and sediment chemistry and landscape and human disturbances, to show responses to stressors.

The IBI uses ten different scored metrics, each of which have demonstrated statistically-significant relationships to different kinds of disturbances.

The 'proportion' metrics are:

- Corixidae Proportion
- Dominant Three Taxa Proportion
- Tolerant Taxa Proportion
- Taxa Richness
- Chironomid Genera
- Leech Genera
- Odonata Genera
- Snail Taxa
- Total Invertebrate Taxa (in this case, the number of genera of Amphipoda, Coleoptera, Diptera including Chironomids, Ephemeroptera, Hemiptera, Odonata and Trichoptera, the number of species of Gastropoda and Hirudinea, and family level identification of Sphaeriidae).

The 'sensitivity' metrics are:

- ETSD metric (number of genera of Ephemeroptera, Trichoptera, Sphaeriidae, and Dragonflies),
- Number of intolerant taxa.

The ETSD metric is a substitute for the EPT (Ephemeroptera, Plecoptera, Trichoptera) metric used in streams, as Plecoptera (stoneflies) do not occur in wetlands due to their requirements for oxygenated water.

There are two means of sampling for invertebrates, and both may be used. Either hand-held dipnets are used to sample the invertebrate community, or activity traps as shown in Figure 6.1 are used to collect the very fast-swimming organisms, and those that are more active at night. Dipnet samples are taken from different areas of the emergent vegetation zone of the wetland. Two dipnet samples of 4-5 sweeps each are taken within the shallow water with a D-frame 600 micron dipnet. The vegetation sampled is emptied onto a 0.5" hardware cloth screen fixed to a 12 x 16" wood frame, which sits over a tray containing the sieved water, within a larger, floatable pan (Plate 6.2). The invertebrates drop down or are pushed through the screen from the vegetation for a period of 10 minutes following each sweeping effort. The organisms are sieved, combined, preserved and returned to the laboratory for identification (generally to the level of genus). This is a laborious process and means that the method cannot be termed a 'rapid assessment protocol'.

Plate 6.2 MPCA staff dipnetting for invertebrates (left) and evaluating samples (right). From MPCA (2004).

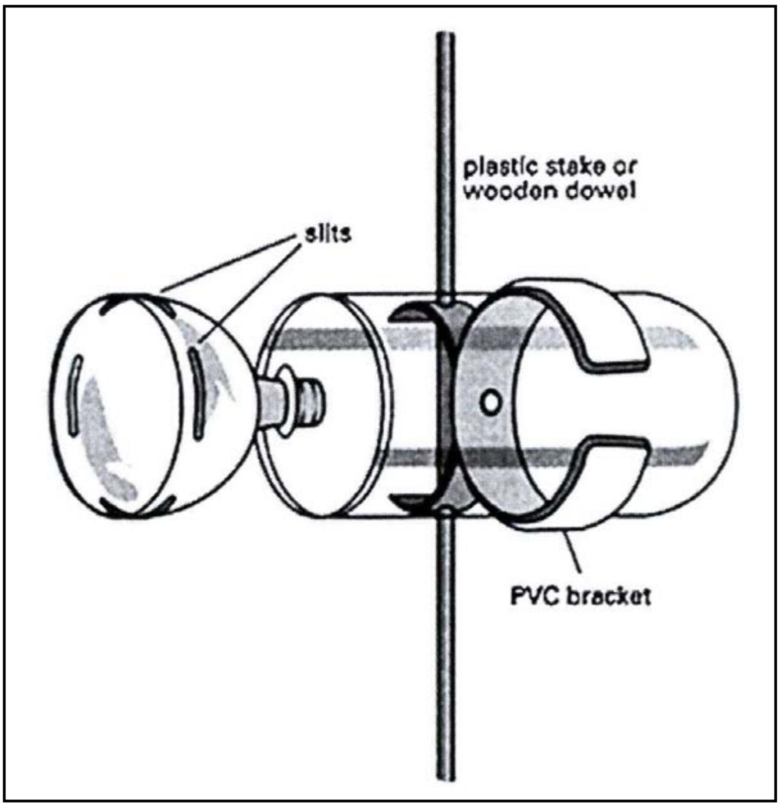


Figure 6.1 A rough design for an activity trap made from a 2l plastic soda bottle. The stake is inserted into the wetland substrate. There are various versions of this design in the literature.

Gernes and Helgen (2002) tested the invertebrate and plant IBIs on a range of 44 large depressional wetlands in Minnesota, exposed to a range of impacts varying from very low to significant. The wetlands hosted 187 invertebrate taxa (genus-level identification).

The authors reported that the invertebrate IBI showed a highly significant relation to the Human Disturbance Scores and to several water quality factors such as turbidity, Chloride and Phosporous. Despite the reportedly low richness of mayflies and caddisflies in the wetlands sampled, the ETSD metric was considered sensitive, and related significantly to the Human Disturbance Score (HDS), Phosphorous, Nitrogen and Total Suspended Solids. The Odonata metric was also considered to be sensitive, and related most significantly to turbidity, Phosphorous, HDS and other factors. The Total Invertebrate Taxa metric related significantly to the human disturbance scores, chloride, turbidity and other chemical factors. The Leech Taxa, Dominant 3 Taxa, the Tolerant Proportion metric and the Corixidae Proportion showed significant, but weaker, relations to measures of human disturbance.

There was often not agreement between the plant and invertebrate indices regarding the condition of reference and impacted sites, and it was thought that the invertebrate IBI may tend to rate sites somewhat higher than the plant index. The authors suggested that further testing and analysis were called for.

New England Freshwater Wetlands Invertebrate Biomonitoring Protocol (NEFWIBP)

(Hicks 1997, Bartoldus 1999)

This method was designed by Hicks (1997) for use on permanently flooded, non-tidal freshwater wetlands of New England. Its primary purpose is to provide a standardised means of assessing the impact of urbanisation on these wetlands. It is also in use to inventorise wetlands within a catchment, to evaluate rehabilitation success, to monitor progress in artificially-created wetlands, and to guide catchment management for risk assessment (Bartoldus 1999).

Fourteen metrics are used to assess ecological integrity:

- Habitat Assessment Score
- Total Organisms
- Total Taxa Richness
- Ephemeroptera, Odonata, Trichoptera (EOT) Richness
- EOT/Chironomidae ratio
- Family Biotic Index
- Percent Tolerant/Percent Intolerant
- Percent Contribution of Dominant Family
- Other Odonates/Coenagrionidae ratio
- Percent Chironomidae
- Percent Oligochaeta
- Community Taxa Similary Index
- Community Trophic Similarity Index
- Invertebrate Community Index

The process followed in developing an index of this nature is as follows:

- Goals and objectives are set for the study.
- The study area is determined as a preliminary desktop exercise.
- Project and reference sites are selected. The wetland type, size and hydrology must be determined. Three reference sites are required per catchment.
- Existing and available information is collected on the reference and project sites.
- At the first field visit, the landscape and wetland characterisation field sheets are completed.
- These data are used to complete wetland Habitat Assessment forms. There are 13 different indicators in various categories. For example: in the 'Landscape' category, the indicator may be dominant land-use, percent impervious surface or percent

natural vegetation. The habitat scoring is in three categories (0, 1-2, 3-4 and 5-6), each of which is attached to criteria. The user selects the criteria that best fit the habitat being assessed, and assign the relevant score. The various scores are summed to calculate the Habitat Assessment Score (Total Score / 78 x 100).

- Aquatic invertebrates are then sampled, sorted, identified and enumerated for all sites. The fieldwork for this exercise takes 2-3 hours, and the follow-up lab work and interpretation is estimated at one day per wetland.
- The invertebrate data are used to calculate the 13 metrics.
- For each metric, the scores for all the reference wetlands are averaged to produce one Reference Score per metric. The project (test) wetland scores per metric are then listed alongside these.
- For each metric, a Biological Condition Score (BCS) is then calculated (the formula for this is not provided), and converted to an alternative 'score' (range 0-6) by referring to scoring criteria table.
- These scores are finally summed to derive the Invertebrate Community Index (ICI). By dividing the ICI score by the maximum attainable score (72), a percentage score is obtained.
- The Habitat Assessment Score is examined relative to each individual metric, to determine the relative impairment of the wetlands being assessed (guidelines in Hicks 1997).
- The Habitat Assessment Score and the Invertebrate Community Index are plotted on graphs for the individual wetlands assessed. The graph is used to describe the impairment of ecological integrity to each site.

The output of the technique is a measure of the biotic integrity of a site relative to that of reference wetlands from the same wetland class and watershed. The method can be used to directly compare similar wetland habitats (with the same classification) within the same geographic region, but cannot be used to compare different habitats (i.e. as defined by classification), or similar habitats from different regions.

The Swan Wetlands Aquatic Macroinvertebrate Pollution Sensitivity method (SWAMPS)

(Chessman et al. 2002)

The SWAMPS method was developed by Chessman et al. (2002) to assess the condition of wetlands in Western Australia. SWAMPS is a biotic index based on macroinvertebrate sensitivity to anthropogenic disturbance, and particularly nutrient enrichment. It is a simpler approach than the previous indices based on wetland invertebrates (which were based on multivariate analysis), using single numbers or an index as a summary of biological data .

The authors of this method recognise that though biotic indices do not provide information at the same level as multivariate analyses, they produce numerical values that can be used as the basis of water quality targets, and do not require as high a level of expertise as do multivariate analyses. These indices have been widely used in rivers and streams worldwide, and have shown sensitivity to different types of human-induced changes in habitat and water quality.

In this index, scores from 1 to 100 are assigned to invertebrate families or species, on the basis of their response to anthropogenic disturbance, primarily nutrient enrichment. The index was developed at both family and species levels in order to test differences in index sensitivity in relation to taxonomic resolution.

The SWAMPS index (at both family and species levels) was developed using data from 40 wetlands located on the Swan Coastal Plain near Perth in Western Australia. Data were collected in January 1989, November 1989 and November 1990. Six samples per wetland were taken at each sampling event, using D-framed sweep nets. Invertebrates were identified to species or morphospecies level, with the exception of the more difficult groups such as

Oligochaeta, Turbellaria, Hydrozoa and Nematoda. Conversion to family-level was done by amalgamating abundances of co-familial species (with the exception of Chironomidae where amalgamation was taken to subfamily, due to the size of this family).

SWAMPS scores ranged from 1 (most tolerant) to 100 (most sensitive). The scoring allocated is presented in Table 6.2. For each sampling event, a separate score was derived for family and species data.

Table 6.3 SWAMPS scores for families of macroinvertebrates found on the Swan Coastal Plain , Western Australia

Family/subfamily	Grade	Family/subfamily	Grade
Aeshnidae	65	Libellulidae	73
Amphisopidae	31	Limnesiidae	64
Ancylidae	72	Limnetidae	50
Arrenuridae	59	Limnocharidae	66
Baetidae	69	Limnocytheridae	73
Bosminidae	64	Lymnaeidae	58
Caenidae	71	Macrothricidae	79
Candonidae	63	Megapodagronidae	36
Ceinidae	50	Mesoveliidae	58
Centropagidae	100	Moinidae	42
Ceratopogonidae	65	(Nematoda)	46
Chironominae	44	Noteridae	36
Chrysomelidae	65	Notonectidae	46
Chydoridae	38	(Oligochaeta)	55
Coenagrionidae	47	Oribatidae	70
Corduliidae	72	Orthocladinae	46
Corixidae	6	Oxidae	63
Culicidae	66	Palaemonidae	83
Cyclopidae	26	Parastacidae	69
Cyprididae	23	Perthidae	78
Cypridopsidae	5	Pezidae	76
Daphniidae	1	Physidae	48
Darwinulidae	65	Pionidae	30
Dytiscidae	50	Planorbidae	66
Ecnomidae	51	Pleidae	67
Ephydridae	59	Pomatiopsidae	52
Eylaidae	53	Ptilodactylidae	56
Glossiphoniidae	29	Pyralidae	66
Halicaridae	64	Sididae	52
Haliplidae	62	Simuliidae	62
(Harpacticoida)	61	Sphaeriidae	53
Helodidae	66	Stratiomyidae	48
Hydrachnidae	22	Succineidae	57
Hydrobiidae	76	Tabanidae	58
Hydrodromidae	66	Tanypodinae	71
Hydrophilidae	60	Thaumauleidae	66
Hydroptilidae	67	Tipulidae	35
(Hydrozoa)	64	(Turbellaria)	63
Leptoceridae	50	Unionicolidae	58
Lestidae	63	Veliidae	60

The family score (SWAMPS–F) and species score (SWAMPS-S) were calculated for each wetland at each sampling event, with each score being derived as the weighted mean of the scores of all the taxa recorded from the wetland. Physical and chemical data were also recorded on each sampling occasion. In order to evaluate performance of SWAMPS, Spearman's rank correlations were calculated between selected physical variables and wetland scores, for both family and species versions for each survey.

The results of the development survey showed general agreement between scores from family- and species-level analyses. In some cases, species scores within a family varied widely due to differing sensitivities within the same family. In most cases, correlation between environmental variables and SWAMPS was significant. Correlation figures were greater for SWAMPS-S than for SWAMPS-F, with high correlation values associated with low SWAMPS scores. There were significant correlations with some measures of eutrophication and other anthropogenically-induced changes to wetlands. ANOVA revealed higher variability in scores between wetlands than within wetlands, with a variance of 88% between wetlands and 12% within wetlands for SWAMPS-S, and 86% and 14% for SWAMPS-F. This suggests that family scores were less repeatable than species scores.

The finding of Chessman et al. (2002) that the species level index had a higher level of wetland discrimination than the family-level index were similar to what had been found in routine river water quality assessment. The overall difference between SWAMPS-S and SWAMPS-F however was not great. Family-level analysis is now used. The lower levels of accuracy and precision in the family-level analysis were largely due to differences in sensitivities among co-familial species. As has been suggested for river water quality monitoring, a family-level index is no substitute for a species-level index, but is appropriate for rapid, less expensive and relatively uncritical evaluations.

This index has not yet been tested elsewhere.

6.4.3 Invertebrates in South African Wetlands

In his report on the biota of South African wetlands in relation to the Ramsar Convention, Cowan (1999) lists an array of invertebrates species found in freshwater and saline wetland environments: marine molluscs (268 species), freshwater molluscs (86 species), amphipods (42 species), crabs (41 species), Ephemeroptera (mayflies, 91 species), Odonata (dragonflies and damselflies, 153 species), Simuliidae (blackflies, 39 species), and Trichoptera (caddisflies, 151 species).

These records have been assembled from work done by individual authors or groups. Although the Ramsar definition of wetland applies to these invertebrate listings (i.e. the lists include taxa found in rivers, estuaries and inshore reefs), the only actual taxonomic records provided, i.e. those for amphipods, crabs, and Odonata - draw a distinction between the biota found in the different types of wetlands.

Crabs: Stewart (1999) lists 44 taxa which occur in a variety of marine and freshwater habitats. Only *Potamonautes sp.B* is listed as occurring in freshwater swamp forests. Families occurring in estuaries, lagoons, and mangrove swamps include Majids (spider crabs), Hymenosomatids (crown crabs), Portunids (swimming crabs), Grapsids (shore, mangrove, marsh and estuarine crabs), and Ocypodids.

Odonata: Samways (1999) presents a list of Odonata (dragonflies and damselflies) occurring in seven different aquatic habitats, the last four of which are considered to represent wetlands under the NWA definition of 'wetland':

4. Wallows
5. Artificial ponds and small farm dams
6. Semi-permanent freshwater pools or pans
7. Permanent freshwater pools, pans, lakes, vleis or marshes.

According to Samways (1999), and notwithstanding recent taxonomic revisions, representatives of the following families, genera or species occur in some or all of habitats 4 – 7 in different regions of the country:
Zygoptera: Lestidae (*Lestes* spp.), Protoneuridae (*Elattoneura glauca*), Platycnemidae (*Metacnemis angusta*), Ceonagrionidae (*Ceriagrion spp,* certain *Pseudagrion spp,* certain *Ennallagma* spp, certain *Agriocnemis* spp),
Anisoptera: Gomphidae (certain *Phyllogomphus spp*, certain *Ceratogomphus spp,* certain *Paragomphus spp*), Aeshnids (*Hemianax ephippigera,* certain Anax spp), Cordullidae (*Macromia spp),* Libellulidae (certain or all species of the following genera: *Orthetrum, Nesciothemis, Palpopleura, Chalcostephia, Hemistigma, Acisoma, Diplacodes, Crocothemis, Bradinopyga, Brachythemis, Sympetrum, Philonomon, Trithemis, Zygonyx, Olpogastra, Rhyothemis,Parazyxomma, Tholymis, Pantala, Trapezostigma, Urothemis, Aethria rezia, Macrodiplax cora).*

Little additional information was sourced on the occurrence and distribution of different invertebrate taxa in South African palustrine wetlands. Researchers at the University of Cape Town and the University of Potchefstroom have sampled invertebrates in different wetland types (Day, pers. comm., Vosloo pers.comm. 2004). It is likely that the information resulting from surveys is stored in various formats with relatively low accessibility (e.g. museum, university, and private records and collections).

6.5 FISH

Not a great deal of literature was sourced regarding the use of fish as indicators of wetland condition. Butcher (2003), in her review of variables used in wetland assessment, reported that no information on wetland fish had been found, and stated that although it was known that 12 indigenous and 6 exotic fish species occurred in wetlands of Victoria, no attempts had yet been made to use fish to monitor wetland in the state. Adamus et al. (2001) reported on literature referring to studies on non-tidal wetlands, with the majority of studies being focussed on lacustrine (lake) fringe wetlands. These authors reflected that in contrast to the energetic development of methods for fish monitoring in rivers, very little had been done in the US to develop IBIs (indices of biological integrity) for fish, specifically those of non-tidal wetlands.

6.5.1 Wetland assessment methods using fish

The 'Use of fish in wetland assessment' guideline is the only module not yet published by the US EPA in their series on wetland assessment (US EPA 2002a-f). This suggests that there is as yet insufficient knowledge or practical experience in this field to formulate a document of this nature.

In Minnesota, Galastowitsch et al. (1998) report on using wetland and stream fish together to represent the condition of landscapes containing a large riparian/wetland component. These authors sampled 15 wetlands, in seven different types, and correlated a number of metrics against a site disturbance score and/or various land cover types measured within 500, 1000 and 2500m of each wetland. The fish metrics tested for their value as indicators in medium-sized floodplain wetlands, using the metrics 'Species Richness', 'Total Abundance' and 'Abundance of Umbra Limi' did not show any consistent patterns (Galastowitsch et al. 1998).

Text Box 6.5 Advantages and disadvantages of using algae as indicators of wetland condition. *From Butcher (2003, citing Adamus & Brandt 1990, US EPA 1998 and personal observation).*

ADVANTAGES

- community metrics well-developed (Index of Biotic Integrity), **though not for wetlands**; many reputed indicators (e.g. carp);
- respond to: DO, pesticides, metals, organic enrichment, eutrophication, acidification, thermal loading;
- most comprehensive set of bioassay data, tolerance to stress known
- can be caged for whole effluent bioassay and *in situ* studies, or avoidance measured using radiotelemetry;
- moderately bioaccumulative;
- integrators of environmental conditions;
- fairly simple identification (except larval stages);
- universal endpoint;
- population characteristics, growth fairly easy to discern;
- contaminants may induce identifiable deformities;
- can be sampled year-round;
- presumptive indicator of hydroperiod (absent from isolated wetlands with complete, sustained drawdown)
- integrate broad, longer-term, landscape-level impacts because of their mobility, high trophic position, and longer life span
- high social importance of most species; existing water quality standards for aquatic life focus on fish

DISADVANTAGES

- mobility makes it difficult to locate specific contaminant sources;
- fish are absent (or present for only brief periods) in most wetlands;
- laborious sampling, field sampling is time consuming and expensive, with high;
- spatial variance and gear problems;
- intensively managed; stocking, angling impact;
- early life stages and non-game species may be difficult to identify.

The metrics used on the different wetland types were as follows:

Wetland type	**Fish metric/s**
Small-sized river floodplains	Fish species richness, proportion of Cyprinids
Medium-sized river floodplains	Fish species richness
Large river floodplains	Proportion of piscivores, total fish abundance, proportion of Catostomids
Non-calcareous littoral wetlands	Total fish abundance
Calcareous wetlands	Species richness, total abundance of fish, proportion of Cyprinids, number of sunfish species
Forest glacial marshes and prairie glacial marshes	Total abundance, richness

A fish IBI trialled on lacustrine wetlands in Florida, US, on 60 lakes reported varied results (Schultz et al. 1999 cited by Adamus et al. 2001). The metrics used in this case were: total fish, native fish, Lepomis, piscivores, generalists, insectivores, and tolerant and intolerant species. IBI scores in this study increased with increasing nutrient levels and lake surface area. This study could not be obtained for a fuller understanding of the approaches used and results reported.

6.6 AMPHIBIANS

Amphibians represent a link between the wetland ecosystem and the surrounding landscape. As a group they are closely linked to wetlands, more so than most birds, mammals and reptiles. For this reason, they are especially vulnerable to alteration or pollution of wetlands (Adamus et al. 2001). The impetus for monitoring of this group would likely come largely from concern over declining populations. This decline is well documented in other parts of the world, however the causes for this are not yet well understood (US EPA 2002d, Adamus et al. 2001).

Amongst amphibians that breed in aquatic habitats, different genera and species have a preference for specific aquatic environments relating to hydroperiod, current velocity and other variables (US EPA 2002d). Some frogs, such as those in the 'true frog' genus *Rana* and the chorusfrog genus *Pseudacris,* live their entire lives in water, whereas others, notably the anurans and many caudates rely on aquatic habitats as a repository for their eggs and a habitat for their aquatic larvae, and live their adults lives in forests or other terrestrial habitats (US EPA 2002d).

6.6.1 Amphibians as indicators of wetland condition

Although they are not well known as a monitoring tool, and only one IBI specifically for amphibians is reported from Ohio, amphibians are considered promising as broad indicators of wetland condition (Alexander pers.comm., Butcher 2003, Carruthers pers. comm., US EPA 2002d, Adamus et al. 1991). This group represents the best opportunity at developing bioassessments of larger landscapes in which wetlands play a role (US EPA 2002d).

The lack of good understanding regarding the relationship between potential anthropogenic causes and amphibian population effects, however, complicates the potential development of metrics (US EPA 2002d). Butcher (2003) suggested that more work was required before incorporating amphibians in a wetland assessment and monitoring programme for Victoria. The situation is likely to be similar in South Africa. A great deal of information exists, but this would need to be integrated and drawn into a framework to develop a means of using amphibians as indicators of wetland condition. Furthermore, amphibian populations fluctuate widely in the hydrologically- and hydraulically-variable setting of wetlands, and at least five years' worth of data would be required on the frog species of a wetland system before any level of precision could be attached to the use of these taxa as indicators of wetland biodiversity or condition (Carruthers pers. comm.).

Certain information can, however, already be used to some extent in *broad,* informal assessment, providing it is in the hands of specialists and it is accepted that the confidence levels of the assessment are relatively low (depending on data availability for the wetland in question). For example, the recently-completed South African Frog Atlas (Harrison 2004) provides distributional and other information on frog species, so that particular species can be linked with different types of wetlands in particular areas. Information is also available in the literature regarding species-specific "call sites", the characteristic micro-environments from which different frog species call (Carruthers pers.comm.). This information can be used by specialists to determine "call site utilisation" in a wetland, which provides some measure of the condition of the system (again relative to *Expected* or *Reference* conditions, and bearing in mind the inherent variability of both the ecosystem and the frog populations). SA frog calls are well-known in certain specialist circles (and are commercially available on CD). Audio recordings of frog calls in a seasonally-wet wetland could be interpreted by specialists to provide a species list for the wetland, and again this could be used together with species lists from similar, unimpacted wetlands, to develop an *Expected / Actual* diversity rating for system. This again could be used to provide broad information on the overall condition of the system.

Inferences could not be made from once-off recordings, however, and a number of field visits to the wetland under a range of different conditions would be necessary to provide some confidence in the assessment (Carruthers, pers.comm.).

At the level of individual species, a postgraduate study has recently been completed in which *Xenopus laevis* eggs and tadpoles were found to be good bioindicators of acidic waters (Haywood 2001). Embryos and tadpoles of this species showed graded responses in terms of their hatching success, growth rate and incidence of malformations when exposed to differing levels of acidity. This approach has been applied in the laboratory and field-tested in a Gauteng stream, and there is further potential to test it in wetlands (Haywood pers.comm.). The relationship between hatching success, survival, growth rate and the frequency of malformations of tadpoles in relation to different concentrations of four heavy metals, Zinc, Copper, Lead and Cadmium, has also been investigated (Haywood et al. in press). In this study, *Xenopus laevis* embryos and tadpoles were shown to be successful bioindicators of the severity of Zn, Cu, Pb and Cd pollution in water (Haywood et al. in press).

There is, thus, a growing recognition of the potential for the use of different amphibian attributes in developing metrics for assessment of aquatic ecosystem health, water quality status, and biodiversity. The development of a method of using frogs as a bioindicator group is considered worthy of proper investigation (Alexander pers.comm, Carruthers pers.comm.), and it is recommended that standards are set up to determine the precision of the method (Carruthers, pers.comm.).

Adamus et al. (2001) suggest that as most individual wetlands have few amphibian species, species richness and community composition may be the best metrics of ecological condition to apply at the landscape scale (i.e. to complexes of wetlands, rather than individual systems). Within individual wetlands, the rates of deformities and the total abundance of tadpoles can be used as an indicator, provided natural reference conditions have been adequately established.

To include amphibians as a part of an assessment study plan, a number of characteristics would have to be borne in mind (Alexander pers.comm., US EPA 2002d, Butcher 2003):

- Amphibian populations fluctuate widely over time and space;
- Sampling would have to be conducted in the wet season to ensure reliable presence/absence data;
- Temporal variation in populations (particularly related to breeding) may differ across regions;
- A number of visits to the site may be necessary to accommodate these characteristics;
- Uplands and wetlands are important in sampling amphibians, as they use both environments;
- A variety of sampling methods may be necessary;
- If the study design monitored several amphibian life stages, it would likely provide valuable information for developing metrics and IBIs;
- Morphological abnormalities are of particular interest and may provide information on stressors;
- When working with amphibians, it would be important to guard against the spread of contamination and pathogens from one study site to another.

They add that a great deal more information is needed on amphibian movements (seasonal and dispersive) in different landscape settings. The advantages and disadvantages of using amphibians as indicators of wetland condition are recorded in Text Box 6.6.

Text Box 6.6 Advantages and disadvantages of using amphibians as indicators of wetland condition. *From Butcher (2003, citing Adamus & Brandt 1990, US EPA 1998 and personal observation), and US EPA 2002d.*

ADVANTAGES

- Small home range relative to larger vertebrates;
- Some social recognition;
- Fairly simple identification;
- Fairly well-established sampling protocols;
- Sensitive to hydroperiod alteration;
- Present in most inland wetland types.

Disadvantages

- Sampling limited to certain seasons in some regions;
- Mostly absent from tidal wetlands;
- Sampling can be laborious;
- Presence can be strongly influenced by natural dispersal conditions.

6.6.2 Wetland assessment methods using amphibians

The US EPA (2002d) guideline on 'Using amphibians in bioassessments of wetlands' provides a valuable reference, including a discussion on the value of using amphibians in bioassessment, monitoring protocols, methods of data analysis, possible metrics, and case studies. Although it is a North American guide, aspects (or principles) are likely transferable to South African conditions.

A small number of studies of wetland condition using amphibians are reported in the literature. Efforts to develop such indices are underway in Ohio, Maryland, Maine and elsewhere in the US (Adamus et al. 2001). The Ohio EPA recently developed an Amphibian IBI (AmphIBI) for use in isolated depressional forest and scrub wetlands. This was reportedly successful for these types of wetlands but did not work well on wetlands dominated by emergent vegetation (Butcher 2003).

Galastowitsch et al. (1998) used amphibians, alongside other biota (e.g. fish), to evaluate the condition of landscapes in Minnesota with a large riparian and/or wetland component. Fifteen wetlands, belonging to four wetland types, were sampled. The following metrics showed positive or negative correlations in one or more wetland types, with a site disturbance score and/or various land cover types (measured within 500, 1000 and 2500m of wetlands): Total Abundance, Species Richness, and Abundance of Leopard frog.

6.7 WATER BIRDS

Wetlands are important areas for breeding, migrating and over-summering wetland birds (e.g. Creighton et al. 1997). Water birds include waterfowl, wading birds, shorebirds and many songbirds (Adamus et al. 2001). Birds may detect aspects of wetland landscape condition that are not detected by other indicator groups (US EPA 2002e). The importance of bird-mediated dispersal of biota in maintaining wetland condition on regional and larger scales, and the connectivity of wetlands at a landscape scale, is reflected on by Amezaga et al. (2002). These authors encourage more emphasis on the distribution of wetlands in space rather than on wetlands of individual importance.

The ongoing threat of wetland loss due to human activities and the associated loss of water fowl (as they tend to be termed in the US) was recognised as a global issue by the Ramsar Convention of 1971, the title of which indicated the importance attributed to birds: *Convention on Wetlands of International Importance especially as Waterfowl Habitat.* In the lower Murrumbidgee River (Australia), extensive loss (80%) of waterbird abundance has been linked to a similarly extensive loss (60%) in wetland area (Kingsford and Thomas 2001, cited by Butcher 2003).

6.7.1 Birds as indicators of wetland condition

Many nationally and internationally important wetland sites are listed on the basis of the birds found at that wetland (Butcher 2003). For this reason, birds are sometimes valued as surrogates, or indicators of wetland condition. However, Butcher (2003) suggests that the link between waterbird numbers / species composition and attributes of ecological character in wetlands needs to be firmed up through research.

Nutrient enrichment of water alters the vegetation structure and the availability of prey, indirectly affecting wetland bird communities. Waterbird abundance and biomass were positively correlated with levels of phosphorus, nitrogen and chlorophyll in 46 Florida Lakes (Adamus et al. 2001). Excessive nutrients, on the other hand, cause algal blooms which can kill fish, impact on macrophytes by blocking light, and affect bird foraging by reducing the visibility of prey taxa located in the water column (Adamus et al. 2001).

6.7.2 Wetland assessment methods using birds

The development of bird IBIs in the US is in its infancy, but is considered to hold great promise. The US EPA (2002d) guideline on ‘Biological Assessment Methods for Birds’, written by P.R. Adamus, provides information on why to survey birds, what a bird IBI would estimate, what it would tell you, steps in developing such an IBI, what to measure, field survey protocols, and further research needs in this field. The recommendation is that, following the classic approach to IBI development, research should be focussed on spatial changes in bird communities across a suite of wetlands that reflect a gradient of human disturbances, to establish which groups are suitable indicators of wetland condition and at what scales.

No studies relating to the development or use of bird IBIs in wetlands were sourced. Adamus et al. (2001) allude to studies which contrast the bird communities of developed, urban settings with similar habitats in rural, undeveloped settings, both at individual paired sites and at a larger spatial scale, reflecting gradients of human disturbance. The authors comment that these studies have indicated the potential usefulness of using bird species composition (wetland birds in particular) as an indicator of shifts in land cover, fragmentation of habitat, and other human disturbances at various scales.

The link between macroinvertebrates and wetland birds has also been explored. One study these looked at distribution and abundances of macroinvertebrates and seeds used by six species of breeding ducks and shorebirds in four wetland habitats (Gammonley and Laubhan 2002). However, patterns of abundance in the food resources were not reflected in the foraging patterns of these birds, indicating that factors other than food play a role in selection of foraging sites by birds. This study indicates that analysis of food resources and abundance can be used to describe the functional role of certain habitats, but may not provide information linking birds to particular habitat types.

Text Box 6.7 Advantages and disadvantages of using birds as indicators of wetland condition. *From Butcher (2003, citing Adamus & Brandt 1990, US EPA 1998 and personal observation).*

ADVANTAGES

- High social recognition, particularly waterfowl;
- There are only relatively extensive databases on trends, habitat needs, and distribution;
- Moderately extensive bioassay data;
- Some species (e.g. Wading birds, harrier) are highly bioaccumulative;
- Simple sampling and identification;
- Present in all wetland types;
- Established sampling protocols are available;
- The only suitable indicator of degradation occurring at the landscape scale.

DISADVANTAGES

- In general, community structure is highly controlled by physical habitat, and perhaps hunting mortality, rather than contaminants;
- Mobility makes it difficult to locate specific causes of mortality sources;
- Absent from some wetlands in winter.

6.8 DISCUSSION

This situation analysis suggests that there are a number of avenues to explore regarding the choice of variables for use in wetland assessment. Of those discussed, plants is the group receiving the most attention in South Africa, and appears to be favoured as the most useful indicator of wetland condition here. In the USA, however, members of the US EPA-led BAWWG group seem to favour a multivariate approach which provides flexibility and broader indication of a suite of parameters relating to condition. Typical metrics used for individual biotic variables are presented in Appendix C. The majority of focus in the US is on plants, invertebrates and algae, with amphibians and birds receiving attention, but at a lesser level. Fish are little-used in wetland assessment, but arefavoured for use in floodplain wetlands and in lakes.

The value of the multivariate approach to assessment is in the power of such an approach to directly measure system condition, to screen for impairment, and to detect a range of stressors, some of which may not be revealed by the use of a single variable. This is highlighted in Table 6.3, where the variables discussed in this chapter are presented alongside their sensitivities and their values as indicators. The choice of which variable/s to use on different wetland types should ideally be decided at a regional or water management level, on the basis of what the information requirements are, what is known of the local wetlands and their biota, what skills are available, and what the budgetary constraints of the programme are. Wherever possible, at least two variables should be considered for use in assessment, particularly as this information needs to be applied further in the determination of wetland water requirements. In this regard, consideration needs to be given to what the information requirements of Reserve Determinations are, concerning the biota. It is necessary to think beyond simple bioassessment and the determination of PES, EIS and Ecological Category, and to extend the standard bioassessment approach such that the descriptive (or quantitative) information required to develop links between the biota and the water regime is collected simultaneously in the field. This is already the case in rivers, although standard protocols are only in the early stages of development for this purpose (Kleynhans pers.comm. 2004). Measurements of chemical and physical characteristics should be another standard procedure alongside bioassessment (US EPA 1998b). The development of a relationship between the bioassessment method and a functional assessment method should be explored.

Further discussion is presented in the final chapter of this report (Chapter 8).

Table 6.4 The variables used in wetland assessment, their sensitivities, and their value as indicators

Variable	Sensitive and show clear response to:	Good Indicator of:
VEGETATION		
Algae	Water quality variables (e.g. nutrients, pH, alkalinity, metals, temperature)	Nutrient levels, herbicides, pollution
Submerged aquatic vascular plants	Turbidity, eutrophication, hydroperiod, herbicides, metals, sediment	Nutrient levels, altered hydrological regime; use of herbicides, land-use impacts; metal pollution
Non-rooted aquatic vascular plants	Nutrients	Nutrient levels
Emergent Vascular plants	Nutrients, sediment, hydroperiod	Nutrient levels, land-use impacts; altered hydrological regime
Woody Vascular Plants	Hydroperiod change	Altered hydrology
Variable	**Sensitive and show clear response to:**	**Good Indicator of:**
MACROINVERTEBRATES	Dissolved oxygen (DO), sediment, metals, other toxins, organic enrichment, fish	Water quality impairment, organic enrichment or pollution
Aquatic insects	Hydroperiod change, sediment, nutrients, contaminants	Altered hydrological regime, nutrient enrichment, pollution
Benthic/epiphytic macrocrustaceans (e.g. amphipods, crayfish, oligochaetes, isopods)	Higher sensitivity to contaminants than aquatic insects; bioaccumulate contaminants	Pollution
Molluscs	Highly bioaccumulative of contaminants	Pollution, Alteration in hydroperiod
FISH	DO, pesticides, metals, organic enrichment, eutrophication, acidification, thermal loading. Bioaccumulate contaminants	Hydroperiod, water quality alteration, nutrients
AMPHIBIANS	Hydroperiod alteration;water quality conditions.	Certain species: Heavy metal contamination, water acidity, biodiversity, general condition (when wetland inundated). Alterations in hydroperiod.
BIRDS	Degradation at the landscape scale	Altered landuse and catchment degradation

7 THE ROLE OF ASSESSMENT AND MONITORING IN DETERMINATION OF WETLAND ENVIRONMENTAL WATER REQUIREMENTS

Note: A discussion of the Reserve Determination Process is not a requirement of the Terms of Reference for this project. However, during consultation with the Project Team, there was a strong emphasis on the importance of bearing in mind the Reserve Determination Process when recommending assessment protocol/s for development in Phase 2 of this project. For this reason, it was felt necessary to provide a background to DWAF's current wetland Ecological Reserve Determination process, the perceived shortcomings, and the possible alternatives to explore in its further refinement. This also serves as a basis for understanding the need to consider ways of extending a standard bioassessment-type protocol such that it includes information on the relationship between the biota and the water regime.

7.1 INTRODUCTION

Water resource managers around the world are faced with the challenge of making decisions about the quantity and quality of water required to maintain or restore aspects of aquatic ecosystem structure or function, while ensuring that these systems supply human water requirements. While environmental water allocation has classically focussed on rivers (and wetlands associated with rivers), the need to adapt the relevant approaches to the broader suite of wetlands has been addressed since the late 1990s (e.g. Davis et al. 2001, DWAF 1999).

Determination of the Environmental Water Requirement (EWR) / Allocation (EWA) of wetlands differs from that of rivers in a number of ways. The direct relationship between water quantity and geomorphology applies to rivers, but not wetlands. In wetlands, variation in water quantity results in habitats of different depths (which are characterised by different plant and faunal communities), and largely determines the areal extent of the wetland. Whereas the full length of a river may be examined in a large-scale exercise, wetlands may be assessed at far smaller and more localised spatial scales. Hydrological data are available for many of the rivers in the country, but are lacking for the majority of wetlands. As with rivers, the ability to determine appropriate water allocations is frequently hampered by the lack of information regarding both the pre-impact condition of the wetland, and the requirements of the biota (Davis et al. 2001).

The 8th Conference of Contracting Parties to the Ramsar Convention (COP8) recognised in 2002 that '*to maintain the natural ecological character of a wetland, it is necessary to allocate water as closely as possible to the natural regime. The ecological character of many wetlands has adapted to past alterations of the water regime, yet they still provide important goods and services. A key step in any wetland conservation strategy is to define the desired ecological character of the most important wetlands. In any water allocation decision, it is then necessary to quantify the critical water needs of the wetlands, beyond which their ecological character will change in an unacceptable manner*' (COP8 2002).

The first step in the COP8 guidelines relating to environmental flow allocations (Text Box 7.1) emphasizes the necessity for studies to identify the habitat preferences of indigenous wetland biota at key life stages, and their tolerance for habitat change. The second step requires a characterisation of the ecological character of the wetland (as defined in Section 2.6). The third assumes that the environmental flow allocations have been determined, and requires monitoring to check their delivery and the ecological outcomes. The role of biota in the process is thus clearly defined from the beginning, and the use of one or more standard bioassessment protocols is clearly a requirement for the determination of both ecological character and as a basis for defining the relationship between biota and water regime.

Text Box 7.1 COP8 generic tools and guidelines relating to environmental flow allocations for particular wetland ecosystems. *From COP8 (2002).*

1. Undertake studies to identify the habitat preferences (hydraulic, physico-chemical and geomorphological) of representative indigenous species at key life stages, and their tolerances of changes in habitat.

2. Undertake baseline surveys in wetland ecosystems where water allocations are to be determined, in order to establish their ecological character, hydrological conditions (natural and present-day), water quality conditions (background and present-day), and geomorphological conditions.

3. Design and implement appropriate ecological and hydrological monitoring programmes to establish whether water allocations for wetland ecosystems are being delivered and whether they are having the desired ecological effects.

4. Identify wetland ecosystems which require a high level of protection (including those listed or proposed for listing as Wetlands of International Importance) or which are linked ecologically or hydrologically to Ramsar sites, and determine and implement water allocations for these ecosystems as a matter of priority.

5. Develop or adapt locally applicable tools and test their applicability.

6. Monitor application of tools and refine them as appropriate

(COP 8, 2002)

7.2 S.A. ECOLOGICAL RESERVE DETERMINATION FOR WETLANDS

The first method devised for the determination of environmental water requirements (or the Ecological Reserve) for South African wetland ecosystems was compiled for the DWAF in 1999 by Duthie, Harding, Kotze and Marneweck, and edited by MacKay, de Lange and Duthie (DWAF 1999). It was adapted from the generic Reserve Determination method, which had been developed for use in rivers.

The wetland method was designed to specifically address the water requirements of three of the wetland types included in the classification system of Dini, Cowan and Goodman (1981):

- LACUSTRINE: Limnetic and littoral (near freshwater lakes)
- PALUSTRINE: Flat slope, valley bottom, floodplain (including freshwater marshes, peatlands, springs, swamp forest, and floodplains)
- ENDORHEIC: Permanent and seasonal pans (DWAF 1999, Appendix W1).

Note: Palustrine wetland types and subtypes commonly occur in association with rivers. These types are, however, distinct from the 'Riverine wetlands' as classified by Dini et al. (1998), which refer to actual rivers[5].

The wetland Reserve Determination method was developed for use at the rapid, intermediate and comprehensive levels, for the purposes of compliance with national legislation (National Water Act NWA, No. 36 of 1998). The method was designed to be integrated with the rivers and groundwater components of the Reserve, where appropriate (i.e. where the water regime of either or both groundwater and the river influence the hydrodynamics of the wetland). The water quality and quantity component of the Reserve for wetlands should be set on the following basis:

For Palustrine wetlands fed by river base-flow and flood-flow, the same rules as those developed for rivers may be used to determine the water quality and quantity Reserve until such time as wetland-specific water quality and quantity rules are developed (DWAF 1999).

Conducting a Comprehensive Ecological Reserve Determination:
If the wetland fulfils one of the following criteria, and the impact of proposed water uses may be large:

- Ramsar wetlands or wetlands with potential Ramsar status;
- Wetlands with national or provincial protected status;
- Large wetlands with complicated hydraulics (e.g. Pongola floodplain, Nylsvley, Mkuze swamps);
- Large freshwater lakes;
- Wetlands fed by water sources on which major developments are planned which could cause irreversible damage to the wetlands; and
- Wetlands supporting endangered species.

***Conducting an Intermediate Ecological Reserve determination*:** If the impact of proposed water uses is not large and the wetland does not fulfil the above criteria (see Integrated Manual), conduct an IER determination with one exception:

[5] The rationale for including rivers in the wetland classification was to ensure compatibility with the Ramsar Convention definition of 'wetlands' which includes rivers.

No Reserve Determination: A Reserve determination is not necessary for endorheic wetlands (pans) unless they occur in areas where streamflow reduction activities are planned or where the pans themselves are subjected to water abstraction or waste discharges.

The Reserve Determination method for wetlands is to enter a period of refinement later this year (Weston, pers.comm. 2004). There are a number of key areas of the present method which must be addressed during this process, certain of which are related to the purpose of this report, i.e. the development of protocols to address wetland biotic integrity.

Marneweck (pers.comm. 2004), having conducted preliminary wetland Reserve Determinations of a number of wetlands as listed below, provides insights into the shortcomings of the present Reserve method, and means of addressing these. This provides a context for the following Section, in which recommendations are made regarding development of a protocol for wetland bioassessment.

Wetlands for which preliminary wetland Reserve Determination has been completed based on the current method (DWAF 1999) by Marneweck and colleagues are:

- As River Wetlands (June 2000)
- Wetlands at Haasfontein Colliery (August 2001)
- Nooitgedacht Pan (Olifants Water Management Area, August 2001)
- Kelland Wetland (August 2001)
- Blesbokspruit wetlands (July 2002)
- Gerhard Minnebron Peatland (November 2002).

7.3 FURTHER DEVELOPMENT OF THE RESERVE DETERMINATION METHOD FOR WETLANDS

by Gary Marneweck and Mandy Uys

There are a number of issues concerning the present method for the Reserve Determination for Wetlands (DWAF 1999) which will need to be addressed in the next phase of its development. All those discussed in this section are related, either directly or indirectly, to the primary purpose of this project: the development of a protocol for the assessment of wetland condition, for inclusion in the Reserve Determination process for wetlands.

7.3.1 Wetland classification

Prior to commencing with the Reserve Determination process, the wetland study team leader is expected to visit a representative sample of the relevant wetlands. The first task on site is to classify the wetlands according to the national wetland classification system (as per DWAF 1999, Appendix W1).

As discussed in Section 2.3, several classification systems are used for purposes of wetland inventory in various parts of the world. The Ramsar Classification System for Wetland Type (Ramsar Convention Bureau 1997) is used to varying degrees for a number of applications by over one hundred signatory countries to the Ramsar Convention, but its usefulness for inventory (Costa et al. 1996) and Reserve Determination purposes is limited. The reason for this is that specialists working in the wetland field have found the method difficult and costly to apply, and often find the categories hard to interpret. It is also too costly to try and map wetlands nationally at the level of detail required using this method.

The system successfully used by the United States National Wetland Inventory for almost 20 years, the Cowardin system (Cowardin et al. 1979), is widely regarded as being one of the most comprehensive and versatile wetland classification systems. Currently, a modification of this system (Dini et al. 1998, DWAF 1999 Appendix W1) has been proposed by DEA&T to be the one that should be used nationally for both inventory and Reserve Determination purposes (see Thompson et al. 2002).

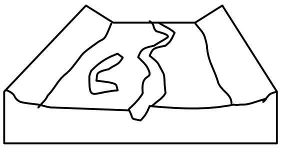
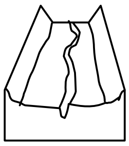
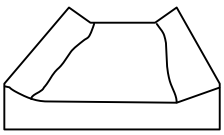
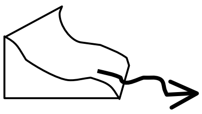
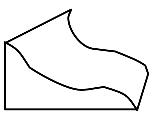
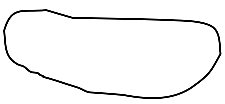
The Cowardin system is a departure from almost all previous wetland classification systems, being structured around the determinants of wetland diversity rather than the needs of a particular group of users. Cowardin et al. (1995) elaborate on this issue by asserting that '*wetland classifications must facilitate mapping and inventory because these data-gathering functions are essential to management and protection of the wetland resource, but the definitions and taxa must have ecological basis'*. The problem is that the Cowardin system is designed for inventory purposes and is difficult to interpret and apply, and is also very expensive (timewise) to implement in cases where resources are limited (Thompson et al. 2002). In South Africa, resources for developing a wetland inventory are limited and this makes implementation of the system impractical. Furthermore, considerable training and skills transfer will be required to implement the system

Towards a more appropriate classification system

As a result of the difficulty in application of the Cowardin system in South Africa, Kotze, Marneweck, Batchelor, Lindley and Collins (2004) have developed a simple seven-type classification system for use in wetland assessment and inventory (Table 7.1). This is based on a second modification of the Hydrogeomorphic Method (HGM) developed by Brinson (1993), and first modified in South Africa by Marneweck and Batchelor (2002). Rather than being biologically-based, the system focuses on the hydrogeomorphic determinants of wetlands and incorporates geomorphology; water movement into, through and out of the wetland; and landscape/topographic setting (see Section 5.3.2).

This conceptual approach intrinsically incorporates both surface and groundwater drivers, and provides first-level insight into the movement patterns of flow and the degree to which the wetlands are open to lateral, vertical and longitudinal exchanges of nutrients, pollutants, sediment, etc. This enables a first-level (preliminary) assessment of wetland functionality. This is the only classification system developed to date in South Africa that incorporates functionality. It also provides a useful framework for assessing complex wetland systems that may include several types within one wetland complex.

Table 7.1 Wetland hydro-geomorphic types typically supporting inland wetlands in South Africa *(from Kotze et al. 2004).* *Contribution usually small ***Contribution usually important */*** Contribution may be small or important depending on circumstances.

Hydro-geomorphic types	Description	Source of water maintaining the wetland	
		Surface	Sub-surface
Floodplain 	Valley bottom areas with a well defined stream channel, gently sloped and characterized by the alluvial transport and deposition of material by water, and oxbow depressions or other characteristic floodplain features such as natural levees.	***	*
Valley bottom with a channel 	Valley bottom areas with a well defined stream channel but lacking characteristic floodplain features. May be gently sloped and characterized by the alluvial transport and deposition of material by water or may have steeper slopes and characterized by the loss of sediment. Water inputs from main channel (when channel banks overspill) and from adjacent slopes.	***	***
Valley bottom without a channel 	Valley bottom areas of low relief, alluvial sediment deposition and having no clearly defined stream channel. Water inputs mainly from channel entering the wetland and also from adjacent slopes.	***	*/ ***
Hillslope seepage feeding a stream 	Slopes on hillsides, which are characterized by the colluvial (transported by gravity) movement of materials. Water inputs mainly from subsurface flow and outflow via a well defined	*	***
Hillslope seepage not feeding a stream 	Slopes on hillsides, which are characterized by the colluvial (transported by gravity) movement of materials. Water inputs mainly from subsurface flow and outflow either very limited or through diffuse subsurface and/or surface flow	*	***
Depression (includes Pans) 	A basin shaped area with a closed elevation contour that allows for the accumulation of surface water (i.e. it is inward draining). It may also receive sub-surface water. An outlet is usually absent.	*/ ***	***

[1] Precipitation is an important water source and evapotranspiration an important output in all of the above settings

NB. It is important to recognise that these are all PALUSTRINE wetland types.

7.3.2 Wetland assessment

The present wetland Reserve Determination method (DWAF 1999) is developed to the level of an Intermediate-level process. For the Intermediate Ecological Reserve (IER), Step 3, the determination of 'Reference Condition' requires a narrative, or if possible a quantitative, description of the 'natural unimpacted' state of the system components (geomorphology, hydrology, water chemistry and biological attributes). The aspects to address to determine reference condition for biological attributes are: vegetation communities and zonation; faunal communities and spatial and temporal distribution; and occurrence of threatened species. Reference Condition represents the baseline against which present conditions can be evaluated, prior to deciding on an Ecological Category (previously termed Ecological Management Class in DWAF 1999).

Step 4 of the method, the determination of Present Ecological State Category (PESC) of the wetland, is presently based on a Habitat Integrity Assessment method modified from that developed by Kleynhans (1999) for evaluating habitat integrity of rivers. There are five tasks: (i) a literature review to assemble a comprehensive database of information pertaining to historic and current aspects of the wetland (ii) aerial photographic assessment of overall habitat integrity of the site; (iii) a site visit and acquisition of local knowledge; (iv) completion and scoring the 'Habitat Integrity for Palustrine Wetlands' datasheet (DWAF 1999, Appendix W4/5) and deriving a score for the site; (v) reporting on the PES of the wetland.

The use of a Habitat Integrity Assessment method based on that developed by Kleynhans (1999) in the wetland Reserve Determination should be revisited. This method was designed for use in rivers, on the basis of riverine processes. It was to be used in wetlands as an interim form of evaluation. It is not considered adequate as a means of assessing either wetland function or wetland biotic integrity, and gives little empirical basis for the categorisation of PES and EIS. It is appropriate that the purpose-driven development of methods for the assessment of wetland habitat (physical and hydraulic), functionality, and chemical and biological condition should be considered, to allow for the construction of an integrated picture (or index) of wetland condition within the landscape. The focus in this project is biological assessment methods, however these cannot be discussed in the absence of information regarding functional assessment approaches.

In the Reserve Determination process used for rivers, a number of biological indices are used to assess river site condition, and to assist in the determination of Reference Condition, Present Ecological State (PES), and Ecological Category. The methods used are:

Ecosystem component	**Assessment Method**
Vegetation	Riparian Vegetation Index (Kemper 1999)
Fish	Fish Assemblage Integrity Index (Kleynhans 1999
Invertebrates	South African Scoring System vs 5, SASS5 (Dickens & Graham 2002).

The Reserve Determination for rivers (quality and quantity) has been extensively refined and conceptually extended over the past decade or more, and it is likely that similar development will be encouraged for wetlands. For example, new aspects of the Ecological Reserve Determination method for rivers presently being applied include the use of the Flow-Stressor Response approach (F-SR; O'Keeffe et al. 2002). This is designed to guide the evaluation of the ecological consequences of modified flow regimes, based on the principles of ecological risk analysis (ERA) (Suter 1993), and using an index of flow-related stress. For the purposes of this method, the term 'stress' is used in a limited sense, to denote the discomfort/damage/undesirable changes experienced by the flow-dependent biota or other components/processes (e.g. water quality), as discharges are *artificially* altered. This definition excludes naturally-occurring stress. A companion method has been developed for applying the concept of habitat types (or classes) in the determination of ecological flows for fish, using the F-SR approach (Klenyhans, pers.comm. 2004.). The method involves assessing the suitability and abundance of different habitat types, which are defined using combination of hydraulic variables (e.g. depth and velocity), substrate and cover features.

In assessing biotic integrity, representative biota of the system should be directly, rather than indirectly, measured. The US EPA (1998a), to illustrate the rationale for this, draws a simple but useful analogy with human health, and a doctor visiting a patient's house. The doctor assesses the environmental conditions in the house by measuring the concentration and amount of different chemicals in the house. If she finds a lot of toxic chemicals in the house, e.g. Mercury, she could infer that the patient is not entirely healthy, without even examining the patient. However if she finds no, or very few chemicals, she could reach an incorrect conclusion by relying purely on the data. The patient may be unhealthy despite the lack of chemicals in the house. The patient may be exposed to chemicals outside the home, or chemicals for which the doctor did not measure the house. The only way to be sure whether the patient is ill, and how badly, is to directly examine the patient. By combining the chemical data with direct measurements of the patient's condition, the doctor can make a more accurate assessment of the patient's health.

Towards the incorporation of functional assessment: WETLAND-ASSESS

The HGM classification system of Kotze et al. (2004), as described in Section 7.3.2, is incorporated into a functional assessment framework or procedure called WETLAND-ASSESS. This method is designed to inform and assist planning and decision-making in wetland and catchment management, and in Ecological Reserve Determination. It allows for rapid assessments of wetlands, so as to highlight their importance in terms of functionality. The procedure is not designed to provide a single overall measure of value or importance of a wetland, nor is it designed to quantify (in monetary or other terms) the benefits supplied by a wetland. It only serves to assist in assigning indices to functions expected to be performed by the wetlands investigated for comparative purposes.

WETLAND-ASSESS is designed for palustrine wetlands, which are defined here as non-tidal wetlands dominated by emergent plants (e.g. reeds), shrubs or trees. 'Palustrine' includes a variety of systems commonly described as marshes, floodplains, vleis or seeps.

Through the assessment of function, WETLAND-ASSESS considers several wetland benefits, which are defined as '*those functions, products, attributes and services provided by the ecosystem that have values to humans in terms of worth, merit, quality or importance'* . These benefits are listed in Table 7.2. They may derive from outputs that can be consumed directly; indirect uses which arise from the functions or attributes occurring within the ecosystem; or possible future direct outputs or indirect uses.

Table 7.2 Wetland benefits (functions) included in WETLAND-ASSESS.

Wetland benefits (goods and services)	Indirect benefits	Hydrological benefits	Flood attenuation
			Streamflow augmentation
			Sediment trapping
			Phosphate assimilation
			Nitrate assimilation
			Toxicant assimilation
			Erosion control
		Biodiversity conservation – integrity	
		Biodiversity conservation – irreplaceablity	
	Direct benefits	*Water supply*	
		Provision of harvestable resources	
		Socio-cultural significance	
		Tourism and recreation	
		Education and research	

The applicability of WETLAND-ASSESS to the Wetland Reserve Method:

For the purpose of consistency and maintaining some links to the existing system being used in the Reserve Determination process, the six wetland systems presently included (DWAF 1999, Appendix W1) could be modified to five as follows: Marine, Estuarine, Lacustrine, Riverine and Palustrine. In terms of the new proposed system, Endorheic wetlands would now be excluded, as they would be one of the Palustrine subtypes[6]. This is because, in the earlier classification, endorheic systems (pans) were defined as being characterised by closed drainage. However, it has since been found that many pans are not closed or endorheic as was previously believed.

WETLAND-ASSESS considers only the Palustrine systems and subsystems, and provides for three levels of assessment, 1 to 3, representing increasing levels of accuracy and confidence.

Level 1 is undertaken as a desktop assessment. It is based primarily on the identification of each individual wetland's hydrogeomorphic type (see Table 7.1). This can be reliably conducted based on interpretation of aerial photos of a 1:30 000 scale or greater viewed through a stereoscope, together with ground verification. The functions assigned to the wetland are those generally associated with the particular hydrogeomorphic type, as defined in the classification. For example, floodplains are characteristically associated with the attenuation of floods and the trapping of sediment. It should be pointed out that there will inevitably be some wetlands which, for reasons that would only become apparent at a more detailed level, will be incorrectly assigned particular functions. Nevertheless, the desktop level assessment provides a useful overview at a landscape or catchment scale.

Level 2 assessment would be suitable for Intermediate-level Reserve Determinations for wetlands. It is based on a rapid field assessment (1-4 hours per wetland depending on the size and complexity of the wetland). Each of seven functions (Table 7.1) is assessed based on a list of characteristics (e.g. slope of the wetland) that are relevant to the particular function. For each characteristic used in the system, there is an information section which provides the rationale for the choice of characteristics together with directions on how to assign scores. Therefore the logic behind the system is open to scrutiny. A basic biodiversity assessment is also included at this level. This has been developed to provide the information required to determine the PESC (Present Ecological State Category) and EISC (Ecological Importance and Sensitivity Category) in the Reserve Determination process. This will however need further development for specific application in the Reserve.

Note: This is the point at which integration of one or more bioassessment methods (e.g. a plant IBI and a macroinvertebrate IBI) could be considered. This would result in an integrated functional and biological assessment system for wetlands, as discussed further in Chapter 8

For Level 2 assessment, the fieldwork is based on a number of datasheets which relate to a number of wetland characteristics contributing to each of the listed wetland functions. For example, for the function of flood attenuation, the characteristics of importance include the relative size of the wetland in the catchment, slope, surface roughness, valley bottom depression, flow pattern of stormflows, run-off potential of soils in the catchment, rainfall intensity, contribution of catchment land-use practices to changing natural runoff intensity, etc. Each characteristic is scored from 0-4, to develop a total score for the individual function.

Level 3 would provide a more detailed description of the wetland, involving the measurement of components such as water quality, inflow and outflow volumes, etc. This would be very data-intensive, require a high level of expertise from a multi-disciplinary team, and be costly to conduct. It could be used to provide the level of detail required for a Comprehensive Reserve. The requirements for this level of assessment have not yet been developed.

[6] Palustrine includes permanent, seasonal and ephemeral systems. Endorheic means that the systems have no obvious surface feed or discharge, and are thus are not obviously connected to a watercourse, refers mainly to pans. Pans can also be permanent, seasonal or ephemeral and many are NOT endorheic.

The key feature of WETLAND-ASSESS is that the level (Level 1, 2 or 3 etc.) of accuracy is based on the objectives of a particular study and the resources available for assessing the wetland/s.

The difference between the Intermediate and Comprehensive Reserve methods is in the level of detail in the information collected for the assessment, and consequently the level of confidence in the Reserve determination. Typically an Intermediate Ecological Reserve (IER) study would be conducted over a maximum period of 2 months, while a Comprehensive Ecological Reserve (CER) study would take 8-12 months or more to complete and would require at least a Level 3 assessment. The existing wetland Reserve Determination Method uses the following guidelines as to which level of study is appropriate:

Conduct a Comprehensive Ecological Reserve Determination: If the wetland fulfils one of the following criteria, and the impact of proposed water uses may be large:

- Ramsar wetlands or wetlands with potential Ramsar status;
- Wetlands with national or provincial protected status;
- Large wetlands with complicated hydraulics (e.g. Pongola floodplain, Nylsvley, Mkuze swamps);
- Large freshwater lakes;
- Wetlands fed by water sources on which major developments are planned which could cause irreversible damage to the wetlands; and
- Wetlands supporting endangered species.

Conduct an Intermediate Ecological Reserve determination: If the impact of proposed water uses is not large and the wetland does not fulfil the above criteria, conduct an IER determination with one exception:

No Reserve Determination:
A Reserve determination is not necessary for endorheic wetlands (pans) unless they occur in areas where streamflow reduction activities are planned or where the pans themselves are subjected to water abstraction or waste discharges.

WETLAND-ASSESS: The 4-step procedure

The 4-step procedure for the use of the WETLAND-ASSESS method is as follows (see Figure 7.1):

Step 1 Objectives for the assessment are defined and the scope of the assessment is determined.

Step 2 A decision is taken as to which of the wetland benefits listed need to be included in the assessment (to meet the objectives).

Step 3 The wetland is assessed using Level 1, Level 2, or a combination of the two.

Step 4 The results are summarised and interpreted, and the objectives revisited to examine what needs to be done to put the results to good use.

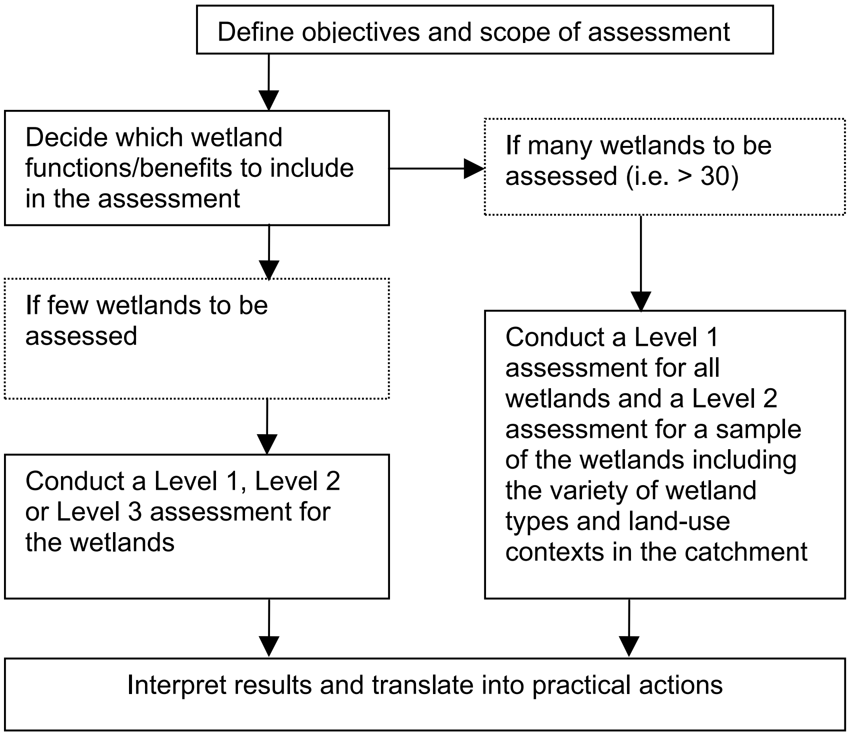


Figure 7.1 A flow diagram showing the procedural steps in WETLAND-ASSESS

The Value of WETLAND ASSESS in the Wetland Reserve Method

i) Ecotyping and determination of Present Ecological State, Ecological Importance and Sensitivity and Ecological Category (previously termed Ecological Management Class, see DWAF 1999)

WETLAND-ASSESS would not detract from grouping wetlands in the study area into ‘ecotypes’ with similar physical, chemical and biological characteristics for the purposes of comparison and extrapolation, as required in the first site visit (DWAF 1999, B/3, B.4). Rather, what it would allow for is a refinement of the ecotyping of Palustrine systems, based on hydro-geomorphic types and functionality.

For Ecoregion Levels I and II, one could still use the ecotyping of rivers as shown in the Rivers Appendix R4 (DWAF 1999b). For Ecoregion Level III, one would still use the existing classification for Lacustrine or Palustrine wetlands, but refine it based on the classification proposed in WETLAND-ASSESS.

- If the wetland is a Lacustrine one (e.g. lake system), then the Lakes Present Ecological Status, Ecological Sensitivity and Importance and Ecological Category tools (DWAF 1999, Appendix W3) could be modified according to site conditions as well as the type of system being considered; or

- If the wetland is a Palustrine system, then the WETLAND-ASSESS tools for determining Present Ecological Status Category, Ecological Sensitivity and Importance Category and Ecological Category (previously Ecological Management Class) could be assessed for each HGM wetland type occurring. These would be determined on the basis of criteria which still need to be developed for each type and each category.

- If the wetland is a pan, proposed methods for determining PESC, EISC and EC are presented in Appendix D.

ii) Determination of the Reference Conditions

It is important that reference conditions are determined per wetland type. *This is also an integral part of bioassessment procedures.* The Reference Condition represents the natural or least-impacted condition for that wetland type in that ecoregion. The present state of a non-reference wetland site is determined relative to the reference condition. To determine the reference conditions, it is necessary to have a basic understanding of the system and its drivers.

The HGM-based classification for Palustrine wetlands, as included in WETLAND ASSESS, provides a useful framework for assessing complex wetland systems that may include several types within one wetland complex. One would then determine a reference condition for each type within the complex.

The classification as defined in WETLAND-ASSESS requires an understanding of the following components for the establishment of a Reference Condition:

Geomorphology:	Terrain unit, landform, substrate type and sediment dynamics;
Hydrology:	Water source, hydrodynamics and periodicity of wetting; and
Water chemistry:	TDS, nutrients, toxic constituents.

7.4 THE AUSTRALIAN FRAMEWORK

7.4.1 Environmental Water Allocations (EWAs) for wetlands

In Australia, two types of methods for determining the EWRs of wetlands are recognised by Gippel (1996, cited by Davis et al. 2001): hydrology-driven and ecology-driven. The hydrology-driven approach requires first the description, then the full or partial restoration of the natural (pre-impact) regime of the wetland. The assumption in this method is that the biota of the wetland are adapted to the pre-impact regime, and that the restoration of this hydrology will result in a balanced, healthy ecosystem. The ecology-driven method requires the determination of the water regime requirements of the existing or preferred biota of the wetland, followed by the provision of that regime. The hydrology-driven approach is considered to be significantly weaker than the ecology-based approach, in that it lacks a focus on the present ecological values of the wetland, and in that the allocation of a percentage of 'natural' flows to a wetland has no sound basis if it is not informed by detailed analysis of the needs of present biota (Davis et al. 2001).

The ecology-driven approach has the most commonality with the South African Ecological Reserve Determination for Wetlands (DWAF 1999, see Section). Ecology-driven approaches are defensible in that they address the current ecological values and the issues affecting the wetland. Objectives are focussed on ecological attributes and strategies devised to supply sufficient water to the system to meet these objectives. The objectives are either focussed specifically on wetland vegetation requirements (as in the case of Roberts et al. 2000) or on a combination of the requirements of vegetation, and birds, or a combination of vegetation, aquatic invertebrates and waterbirds using the system (e.g. WAWA 1995, Davis et al. 1993).

Reports regarding the environmental water requirements of wetlands and their biota

There is little in the literature guiding the development of methods for the estimation of the water requirements of wetland biota. However, two key reports provide useful guidance as to the level at which these requirements are presently estimated in Australia.

Water requirements of plants in floodplain wetlands
Roberts, Young and Marston (2000) produced a guide on the estimation of water requirements for plants of Australian floodplain wetlands[7]. The guide is intended to inform individuals charged with making decisions about water allocations, particularly linked to wetland restoration. The 5-step process is summarised in Table 7.3. The information on the floodplain wetland vegetation and sampling methods could be transferred to other wetland categories.

Framework for environmental flow allocations
In 2001, Environment Australia's 'Environmental Flows Initiative' released a report on the 'Environmental water requirements to maintain wetlands of national and international importance' (Davis et al. 2001). This report focuses on the methods of assessing the success or otherwise of environmental water allocations for maintaining important wetland systems.

The framework for environmental flow allocations provided in this report is a stepwise process, based on a review of contemporary methods and approaches in Australia. Much of the process is similar to that proposed by Roberts et al. (2000). The process is graphically represented in Figure 7.2. **Step 4 of this framework is of particular interest and relevance to this report.** It is summarised below from Davis et al. (2001).

In Step 4, the relationships between biota and the water regime are described. Most attention is on relationships between the water regime and significant communities or species. For example, if a wetland is significant due to the presence of waterbirds, the water regime requirements of waterbirds will be critical. These will include both direct water requirements and indirect requirements (the water regime requirements of vegetation used by waterbirds). The following groups of wetland biota could be considered: algae, submerged plants, emergent plants, trees and shrubs, aquatic invertebrates, fish, waterbirds, other fauna (wetland reptiles, amphibians and mammals). Water regime requirements of biota may be examined for each of the identified wetland zones (Step 1). Water regime requirements for both maintenance and recruitment of individual species need to be considered. **Lack of knowledge regarding these requirements has been identified as an impediment to the determination of environmental water allocations for wetlands** (Allan and Lovett, 1997; Arthington *et al*., 1998; Roberts *et al*., 2000 are cited). The water requirements of biota need to be considered over large spatial scales, and habitats can be assessed as interlinked systems (e.g. wetlands linked to rivers, or wetlands on different continents) if examined in terms of the needs of fauna which move between them, such as waterbirds and fish.

The biotic and hydrological monitoring (Step 11) proposed after the implementation of environmental water allocations is intended to add to the existing knowledge of the effects of different water regimes on wetland biota (see Section 7.4.2).

This proposed framework was applied to a series of case studies in Australia, all of which had different expected management outcomes, such that the variables and indicators measured had to be largely site-specific. The case study on the Thomson's Lake is reproduced in this report as Appendix E, to provide an example of how this method compares to the current DWAF Wetland Reserve Determination approach, and the way in which the relationship between different elements of the biota and the water regime have been established descriptively (Step 4). For the large part, we do not as yet have sufficient understanding of the water requirements and tolerance ranges of wetland biota to be in a position to incorporate these needs into a quantitative assessment method.

[7] Many floodplain wetlands are listed as wetlands of national and international significance because they support large waterbird populations after flooding.

Table 7.3 The five steps for determining the water requirements of floodplain wetland plants. *From Roberts et al. (2000).*

Step	Description
1. Describe ecology, hydrology, uses and values of the floodplain wetland (desktop exercise)	Description means the floodplain's water balance, its ecology (particularly relating to vegetation) and its comprehensive uses and values. Information: climate, surface and groundwater flow, plant water-use or evapotranspiration data, soil types, vegetation or landuse maps, historical information.
2. Set vegetation-related management objectives	These include objectives relating to any producetive or economic uses that depend on vegetation condition. To quantify objectives, appropriate vegetation measures must be identified (e.g. area of each plant community, mix of plant community types, species diversity etc.).Target values are then set for these measures
3. Describe relationships between vegetation and flow regime	These may start with description of natural vegetation and hydrology, and description of current vegetation and hydrology. A fair amount is known about the water regime tolerances of common or widespread plant species. Measures of health or condition of plants have not been well-linked to specific environmental stressors. If no quantitative information is available, expert opinion should be sought.
3a. Improve the relationships to generate new ones	In this sub-step, new data on hydrology are required to describe the spatial and temporal variations in water regime, and new data on vegetation are required to describe the spatial and temporal variation in vegetation.
4. Determine the water regime to achieve management objectives	This involves using the vegetation-hydrology relationship to predict likely vegetation condition, across the floodplain wetland if possible, given a changed water regime. These predictions may be simple (descriptive) or more complex (numeric). Spatial simulation of the water regime may be limited to water balance calculations. A Digital Elevation Model (DEM) may be required to provide accurate predictions of water depth. A hydraulic simulation will be required if surface flow velocities differ greatly from one flood event to the next or from one part of the floodplain to the other.
5. Trade-off process with other water uses	This step is contingent on achieveing a quantitative description of which water regimes will be needed in the river and on the floodplain wetland to achieve the objectives set. In this step, trade-offs are made with elements outside of the floodplain, e.g. water users.
5a. Refine vegetation management objectives	

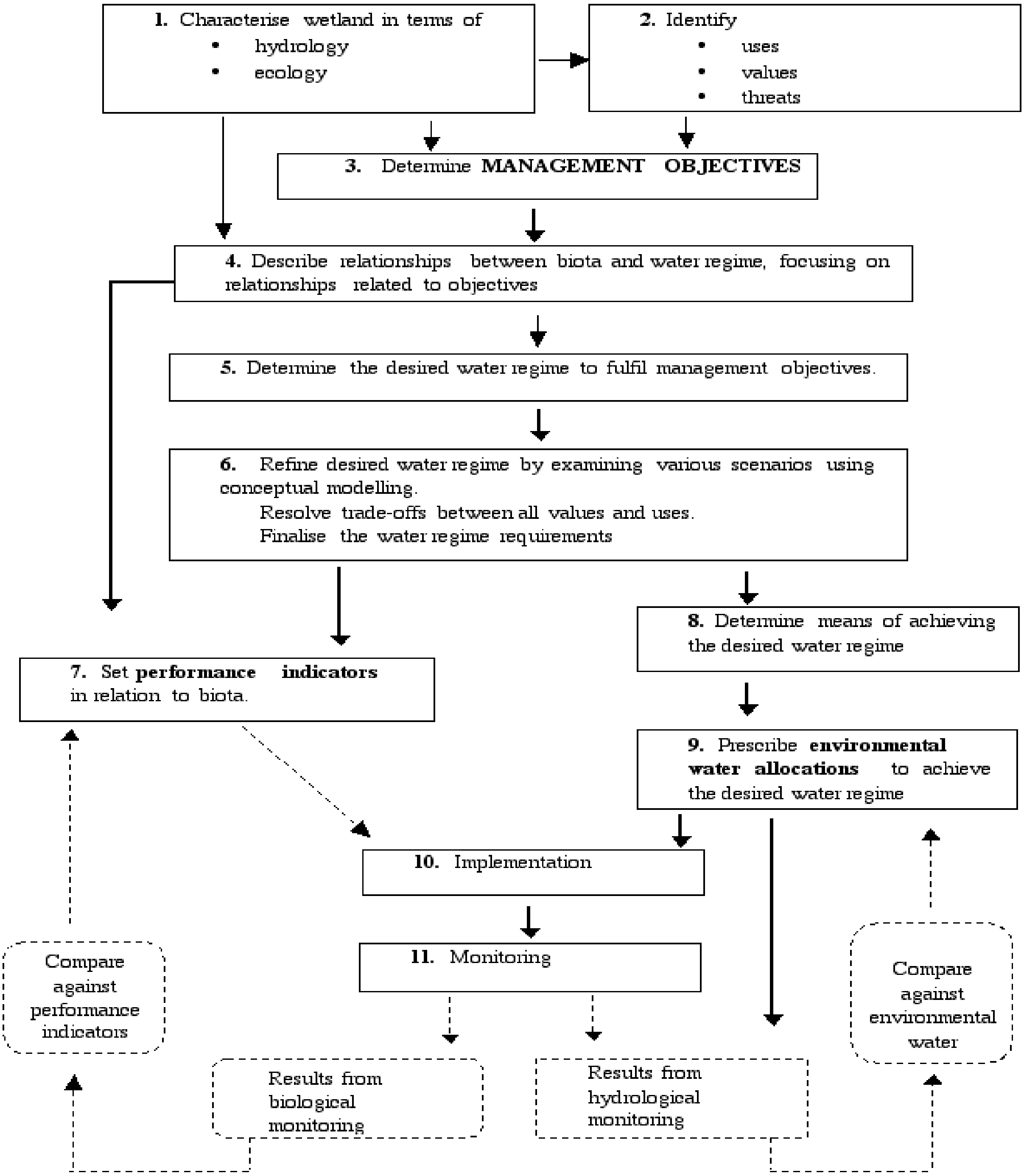


Figure 7.2 Framework for the determination of environmental water allocations. Feedback loops are indicated by dashed lines. *(From Davis et al. 2001)*

7.4.2 Monitoring the outcomes of EWA delivery

A number of EWAs have been implemented in Australia and the ecosystem outcomes thereof evaluated through monitoring on an ongoing basis. Reid and Brooks (1998) provide a comprehensive review of issues and monitoring protocols in their development of a generic monitoring programme to detect short- and long-term changes in wetland ecosystems in response to environmental water allocations. In reporting on a pilot study on methods for monitoring the effectiveness of environmental water allocations in a number of River Murray wetlands, Reid and Brooks (2001) and Reid et al. (2001) make a strong case for the role of monitoring with a variety of hydrologically-sensitive indicators. They recommended a range of physical, chemical and biological indicators for use in monitoring change in wetland health in response to the implemented EWAs, and provided information on a range of biota including biofilms, zooplankton, birds, fish, mammals, reptiles and fringing vegetation. Their results reportedly suggest that plants are good and cost-effective indicators of hydrological change, based on the strength of correlations between various hydrological variables and macrophyte community structure. Reid et al. (2001) report that the macroinvertebrate data are likely not suitable for monitoring of the effects of environmental water allocations, however they are considered well suited to use in assessment of wetland health or condition. The authors point out that knowledge is limited regarding both the indicator potential of aquatic macroinvertebrates, and the nature of the relationship of both variables with wetland hydrology and ecosystem health. According to them, the major constraint represented by the use of this group of indicators is the time required for data analysis.

Limitations on the project were that the wetlands used in the study were from different flooding thresholds, so there was the risk of confounding effects in the experimental design; and also invertebrate data were only collected once.

7.5 WATER REQUIREMENTS OF WETLAND BIOTA

There is not extensive information available in the international literature regarding the relationship between the wetland water regimes and the biota which occupy these heterogenous systems and their fringes. The paucity of knowledge in this regard, and the problem that this creates in determination of Environmental Water Allocations, is commented on by various authors, including Roberts et al. 2000, Arthington 1998, and Allan and Lovett 1997. In Australia, Roberts et al. (2000) commented that although a reasonable amount was known about the tolerance ranges of certain plant species in some regions, this information had rarely been collated. They noted that tolerance ranges may include conditions which were marginal for a species rather than optimal. Roberts and Marston (1999) compiled a summary of current knowledge of the water regime requirements for certain plant species in the Murray-Darling Basin.

In South Africa, there is a fair amount of information regarding the water regime requirements of wetland plants, however this is largely anecdotal and unpublished (Marneweck, pers. comm. 2004). The approach currently adopted is the use of four categories that are used to decide whether or not any individual plant taxon is likely to indicate the presence of hydric soils (sensu Reed 1988). This system is illustrated in Table 7.4.

Table 7.4 Classification of plants according to occurrence in wetlands, based on U.S. Fish and Wildlife Service Indicator Categories (Reed, 1988)

Classification	Description
Obligate wetland (ow) species:	almost always grow in wetlands (>99% of occurrences).
Facultative wetland (fw) species:	usually grow in wetlands (67-99% of occurrences) but occasionally are found in non-wetland areas.
Facultative (f) species:	are equally likely to grow in wetlands and non-wetland areas (34-66% of occurrences).
Facultative dryland (fd) species:	usually grow in non-wetland areas but sometimes grow in wetlands (1-34% of occurrences).

Note: only the ow and fw species are considered as wetland indicator species.

Based on these categories, a provisional list of indicator plants was drawn up by Kotze and Marneweck (1999) and is presented in Appendix E. While this method provides a basic indication of tolerance of wet soil conditions, it does not allude to the specific water requirements of each of the species listed. Further work is required to update the list in Appendix f to a national suite of species, and to include at least a preliminary indication of the water requirements for each species in order to develop a comprehensive indicatory category list of plants for use in the SA wetland Reserve Determination process.

Marneweck (pers.comm. 2004) reports that considerable experience and data for the development of such a list is available in South Africa. He suggests that experience and existing research on wetland plant life-history strategies could be used to refine these indicator categories for use in the Reserve method. This could be achieved by contracting relevant specialists from other regions to assist with development of such a list. A workshop could also be held to refine the categories for specific application to the Reserve.

The hydraulic habitat requirements of fish species at different times of their life cycles are fairly well known for rivers, and some of this knowledge would be relevant to wetlands, particulary floodplain wetlands and certain lakes (Kleynhans pers.comm. 2004). The physical and hydraulic habitat requirements of the major invertebrate taxa are broadly understood for rivers, however it is not certain how these preferences would be adjusted in a wetland environment. If one does not understand water requirements, it is not easy to estimate biotic responses to adjusted hydrological regimes.

This paucity of information represents a potential obstruction in the further development of EWA or Ecological Reserve Determination methods for wetlands, and should be addressed in the development of bioassessment protocols (Phase 2 of the current study).

7.6 ASSESSING THE WATER REQUIREMENTS OF WETLAND BIOTA

Where there is scarce information available on the water requirements of biota of a wetland, these relationships need to be established as one step in the process of determining environmental flow requirements of the system. Although there are few guidelines for achieving this methodologically, Roberts et al. (2000) discuss ways of developing vegetation-hydrology relationships for floodplain wetlands particularly, at the level of species, communities or the entire floodplain. The process involves adapting sampling protocols designed for terrestrial vegetation, in consultation with experienced plant ecologists. The authors comment that the selection of which to use should be determined by the vegetation-related management objectives, available time and resources, and the type and quality of the hydrological data. The authors recommend that the goal should be the use of plant communities or a suite of species rather than single species (unless the species is considered an indicator or surrogate for a whole community; or has a water regime preference which is far narrower than the majority of plants present). The advantages of using a community are that community level information is a better integration of ecosystem processes, spatial variations and temporal differences. The disadvantages are that the plant community is dynamic and changes with changes in environmental conditions. Also, dominant species may change in seasonal systems. A keystone species could also be used, however Roberts et al. (2000) commented that the identification of such species was a relatively new concept, and that there were no formal protocols available for this as yet.

The subject of interest in determining water regime requirements is the *response* of the community to changes in the water regime. This is similar to the approach adopted in the Flow-Stressor Response method of O'Keeffe et al. (2002), used within the rivers Ecological Reserve Determination process (as described in Section 7.3.2). In the approach of Roberts et al. (2000), one or a series of the components of the water regime could be used, e.g. depth or frequency of inundation as a univariate analysis, or a combination of the two or more components as a multivariate analysis. These authors note that although water depth is the variable of greatest relevance to plants, data on water depth are seldom available for wetlands (particularly large wetlands where depth variability is high) and these must be obtained either directly through field studies, or indirectly through water balance calculations from existing data.

Plant or community responses to the selected regime components are described in terms of abundance, character (features e.g. perennial or annual, exotic or indigenous, reproductive strategies), and condition (vigour, physiological condition, whether a population is self maintaining, etc). There may be a number of measures for each, with measures of condition being emphasised. Changes in the water regime would produce a stress to the plant – either water stress to the aerial portions of the plant, or oxygen deprivation in the root zone. These stresses would have particular symptoms which should be reflected in the measures of condition. The type of vegetation data to use, and the method chosen, would be determined by the use to which the vegetation-hydrology relationship would be put: to describe, to quantify, or to predict. The recommended procedure is predictive modelling, i.e. the use of these relationships to predict the likely future state of floodplain wetland vegetation as a result of proposed changes to water regime.

The EWA framework of Davis et al. (2000), which includes describing the relationship between the biota of the system and the water regime (Step 4, Figure 7.2), is considered a suitable model for transfer to South African conditions by Marneweck (pers.comm. 2004). A case study from Davis et al. (2001), to illustrate the use of this framework in an Australian wetland system, is presented in Appendix F.

8 RECOMMENDATIONS

8.1 INTRODUCTION

The aim of Phase I of this project was to conduct a literature survey to enable a Situation Analysis regarding the status of wetland bioassessment in South Africa and the world, and to make recommendations regarding the development of a wetland 'integrity index' for use in determining wetland condition, for incorporation into the wetland Reserve Determination process, and for future inclusion in the National Aquatic Ecosystem Health Monitoring Programme (River Health Programme).

The findings of this report, which result from literature review, discussions, correspondence and workshopping, serve as the backdrop for a number of recommendations to the Study Team for a 'way forward' in Phase 2 of this project (*Development of a method for assessment of wetland condition*).

It is urged that these recommendations should not be viewed as a final, prescriptive outcome of Phase 1, but should be taken forward into a period of review and discussion within the Project Team, in consultation with members of the Steering Committee and relevant wetland specialists. The ideal format for this process would be a workshop.

The recommendations provided here take into account:

- The requirements of the Terms of Reference of Phase 1 of this project;
- The format and requirements of the DWAF Water Quality Monitoring Strategy (DWAF 2004);
- The requirement of the wetland Reserve Determination process for a revised wetland assessment protocol (to replace or augment the current form of assessment, the Habitat Integrity method adapted from Kleynhans 1999);
- The current lack of a standard, ecologically-or biologically-based assessment method for South African wetland ecosystems (although Mondi Wetland Project currently has a study to develop a plant assessment protocol, as described in Section 4.3)
- The explicit (or implicit) need for a tool to evaluate wetland condition, within the processes developed by a number of external wetland projects (e.g. Dickens et al. *in prep,* Steps 3 and 4; Ellery *in prep.).*
- The current level of knowledge of the biota and ecology of South African wetland ecosystems. It is inferred from this study that vegetation is the best known and understood of wetland biota in this country for the suite of different wetland types and ecoregions encountered. The key drivers for plant distribution and community structure in wetlands are hydrology and soil type (Marneweck, pers. comm.). The relationship between plant zonation, plant community structure and wetland water regime is fairly well understood, at least for the vegetation of particular ecotypes and regions. The invertebrates and fish of most wetland types have not been extensively studied.
- The financial resources and human capacity available to undertake wetland assessment in South Africa, relative to those in the US and Australia.
- The need for assessment protocols which do not rely excessively on qualitative impressions and human or specialist judgement; so that the method is repeatable and objective.
- The resultant need for one or more standardised, scientifically-sound (but conceptually simple) form/s of wetland assessment which would be transferable across programmes, agencies or processes; could be applied in the long-term monitoring of different types of wetlands; and most importantly would be suited for use in the

determination of Present Ecological State Category (PESC), Ecological Importance and Sensitivity Category (EISC) and Ecological Category (EC) within the Wetland Reserve Determination Process.

- The recognition that this method would have to generate information which would be useful (outside of the method) in assisting one to understand the relationship between the wetland water regime and the relevant biota.

8.2 REQUIREMENTS

Few of the wetland projects currently underway in South Africa include assessment of wetland condition using biota. The proposed delineation procedure for wetlands (DWAF, *in prep*) uses vegetation as an indicator of wetland zonation and condition, following a broad vegetation classification procedure devised by Kotze and Marneweck (1999). The Mondi Wetland Project vegetation-based index of condition is used at a local scale to inform wetland management actions (Walters pers.comm. 2004). Assessment of wetland condition is also done on the basis of specialists' experience of particular wetland types, their hydrogeomorphic settings, and the vegetation that characterises them.

Several recent reports and wetland projects indicate that there is recognition of the requirement for both assessment and monitoring protocols for use in wetlands. The DWAF Monitoring Strategy (DWAF 2004) requires that all aspects of the hydrological system (including wetlands) are monitored for the purposes of Integrated Water Resources Management (IWRM). The DWAF Resource Quality Services directorate has specified that an integrated index is required for the evaluation of wetland health, not only for Reserve Determination purposes, but also for possible future application in the River Health Programme (see Terms of Reference, this study). Dickens et al. (*in prep*) introduce the possibility of monitoring wetland 'health' and present three of invertebrate Indices of Biological Integrity (IBIs) from the US as examples of what is possible in this regard, in a catchment context. The Mondi Wetland Project (MWP), in recognition of the need for wetland assessment, is currently developing a plant-based wetland assessment method for in the management of wetland impacts (Walters and Lindley, pers. comm. 2004). The WRC Wetland Rehabilitation Project includes, amongst its aims, the determination of present wetland condition and the use of this information to generate rehabilitation objectives (Ellery, 2003).

The focus of wetland assessment and monitoring should be on measuring ecological character as a means of assessing wetland condition (e.g. Butcher 2003). To do this, a suite of standard protocols and procedures are required for measuring the various components of the ecosystem. Wherever possible, a number of different biotic components of the system should be measured, and it is likely that the variables selected will vary according to wetland type and ecoregion.

Regarding the biota, the requirement is for an assessment and monitoring system that will incorporate a series of options for bioassessment protocols, and that will fulfil the following:

- Be suited both to the purposes of wetland assessment (first-level evaluation to determine present state, impacts and threats, and set monitoring objectives) and monitoring (of the selected variables over the longer term);

- Provide a range of options such that the monitoring exercise can be tailored to the available budgets, capacity, and ecoregional conditions;

- Be suited to incorporation in the DWAF wetland Reserve Determination process, and thus:

- Be scored in such a way that different scoring ranges can be related to different ecological condition categories (for use within the new DWAF classification method);
- Provide sufficient information on taxa present, relative abundances, community structure, etc., to be used in determination of Present Ecological State, Ecological Importance and Sensitivity, and Ecological Category, and also in assisting later steps in the Reserve Determination process, for example the assessment of the effect of different water regime scenarios on the biota. To be effective, this requires that wherever possible autecological studies of the various biota be initiated, possibly at university or programme level.

- Be simple enough to be used by trained technicians with a background in the identification of the relevant biota (e.g. plants, invertebrates, fish, birds), and an understanding of the ecological context in which these occur.

- Be sufficiently pragmatic and self-evident to be managed and operated in individual WMAs by the relevant CMAs (as required by the DWAF Monitoring Strategy).

- Be cost-effective such that seasonal monitoring is enabled (as with the indices used in the River Health Programme and the river Reserve Determination processes).

- Be applicable over spatial and temporal scales (i.e. adaptable to the conditions occurring in different wetland types and in different ecoregions). As with the ongoing development of IBIs in different parts of the U.S., one would ideally adopt a generic approach and adapt this for use in each different wetland type, and within each ecoregion. It is likely to be a long process to generate methods suited to (a) for each of seven types and (b) for these types within each ecoregion. The challenge is to ensure that the scoring of each different version of the method is devised in such a way as to allow comparison between the quality of wetlands of one type relative to another, and in one region relative to another.

- Produce data and information that can be interpreted in the context of the historic and current wetland regime (which should be determined first); soil types; and information on system function (derived through the use of a functional assessment protocol).

8.3 CONSTRAINTS

There are a number of constraints to be recognised in the development of a South African method for the assessment of wetland condition.

- Little is presently known about the *ecological* state of South Africa's wetlands. On the whole, reference standards or benchmarks have not been determined for the various wetland types (Walters, pers.comm. 2004).
- Biocriteria for different wetland fauna and flora have not been established.
- The bulk of available information on wetland biota in SA pertains to wetland vegetation, and much of this is anecdotal and not accessible in published literature.
- Identification of wetland vegetation and wetland plant indicators requires specialist taxonomists (DWAF 2003).
- The identification of other wetland biota, particularly invertebrates, algae and diatoms, requires the skills of trained and experienced fieldworkers or technicians. (The availability

of individuals with experience in aquatic invertebrate identification in SA is considered an opportunity)

- There is as yet no formal commitment to initiate a monitoring programme for wetland condition in SA. This is a constraint in that, ideally, the decision as to which assessment protocols to develop should be made in the context of a greater assessment and monitoring framework or strategy. There is, however, a stated intention to include wetland monitoring in the River Health Programme at some time in the future (*this study, Terms of Reference*)).

8.4 RECOMMENDATIONS

8.4.1 Devise a framework for wetland inventory, assessment and monitoring

Phase 1 of this project has involved reasonably extensive consultation with various wetland experts in the country, and review of the available literature on South African wetlands and the numerous projects and programmes dedicated to their wise use, management and conservation. What has come to light, through this process, is the lack of an integrated, multidisciplinary, national-level programme to specifically address the question of assessment and monitoring of wetland condition in South Africa.

Although such investigations may be implicit in many of the projects underway within Working for Wetlands and the Mondi Wetland Project, *inter alia*, there is (as far as is known) no framework in South Africa to ensure that the following are addressed:

(i) the state of the resource, and trends in, wetlands in the country;
(ii) the gathering of crucial biodiversity information;
(iii) the development of an empirically-based description of the natural (reference) ecological condition of the extensive wetland types;
(iv) a standard set of protocols for assessing wetland ecological character;
(v) an understanding of the nature, distribution and extent of the key threats to wetlands; and
(v) a standard format for setting objectives and targets for future wetland condition and wetland Resource Quality Objectives.

The 8th Conference of Contracting Parties to the Ramsar Convention (COP8), which was focussed on Africa's wetland management strategy under NEPAD (New Partnership for Africa's Development), recommended that: '*The wetland component of NEPAD should build on the past 20 years of effort in the wetland sector and not duplicate other initiatives.* ***Working for consensus at the local, national and sub-regional levels is a prerequisite for the adoption and the achievement of a common vision for wetlands****'*. This message should be endorsed and embraced by the South African community of wetlanders and scientists.

With the aforementioned in mind, the **first recommendation** is that a number of key agencies, organisations and programmes/projects collaborate to develop a framework for a Wetland Inventory, Assessment and Monitoring System (WIAMS), following a combination of two approaches: the DWAF procedure for establishment of monitoring programmes (DWAF in prep.; see Text Box 3.1), and the guideline produced by Ramakrishna (2000, Appendix B) for the development of a WIAMS. This system could form the basis of a long-term monitoring programme for wetlands. To a DWAF water resource manager with integrated water resource management (IWRM) responsibility, such a programme must have links with the National Aquatic Ecosystems Monitoring Programme (River Health Programme) and the Estuaries Monitoring Programme, since these also address the health of the ecosystem (DWAF 2004).

Partners in this endeavour could include:

- Department of Water Affairs and Forestry (DWAF; various directorates including Resource Quality Services and Resource Directed Measures);
- Department of Environmental Affairs and Tourism (DEAT);
- Department of Agriculture (NDA) including the Landcare Programme;
- Mondi Wetland Project (MWP);
- NEPAD Environmental Initiative: Wetland Component;
- United Nations Development Programme (UNDP);
- Water Research Commission (WRC),
- Working for Wetlands (WfWetlands);
- Working for Water (WfW)
- World Wildlife Fund (WWF) Living Waters Programme.

Other organisations may also be considered important in this process.

The logic of this recommendation rests in the fact that the majority of these bodies are already in some way contributing to the attainment of the goals of wise use, conservation and management of wetlands in a catchment context. Most are engaged in the development or application of methods and activities which either are, or could be, used in generating the following outcomes:

- Integrated water resource management and protection in a catchment context (DWAF, WRC, MWP, WWF);
- Determination of wetland environmental water requirements (Reserve Determination) (DWAF);
- Water use licensing (DWAF);
- Monitoring of water resource quality (DWAF);
- Setting of Resource Quality Objectives and targets (DWAF);
- Wetland delineation (DWAF, MWP);
- Conservation of aquatic biodiversity (DEAT);
- Sustainable livelihoods (UNDP);
- Evaluation of the impacts of planned developments (DEAT);
- ‘State of Environment’ reporting (DEAT);
- Wetland inventory (WfWetlands, Norwegian government);
- Erosion control activities (NDA);
- Wetland Rehabilitation (Working for Wetlands, Mondi Wetland Project, WRC);
- Wetland use, management and conservation in a catchment context (WRC, MWP, WfWetlands).

As inventory processes are already underway (Section 3.2.3), a consolidated effort to establish a WIAMS would fast-track the development of wetland assessment and monitoring methods, could ensure optimal use of both funds and expertise, and would avoid replication of effort.

Such a WIAMS framework would, optimally, be established with ‘joint custodianship’, and the contributing partners would need to retain their philosophical and operational independence. The existing partnership between WfWetlands, MWP, DEAT, NDA, WRC and Working for Water serves as an example of such a successful collaboration. Given the terms of the DWAF Monitoring Strategy (DWAF 2004), and the role of DWAF in the monitoring and protection of aquatic resources in SA (NWA 1998), it is likely that DWAF and/or delegated CMAs may need to play a coordinating role in developing and implementing a wetland monitoring programme based on such a system.

The WIAMS example (Appendix B) has a number of advantages. While providing a standard format for assessment and monitoring, it allows for flexibility in the choice of what method to apply, dependent on the information needs, the purpose for which the information is to be put, and the biogeographical setting of the system/s to be evaluated.

A South African system modelled on this approach would provide the flexibility required by the new DWAF Monitoring Strategy (DWAF 2004): i.e. enabling individual CMAs to select the assessment method/s most appropriate to their ecoregions, wetland types, knowledge base and agency logistics, whilst retaining the coherence of a national standard approach. Ideally the scoring method incorporated would be common across regions, i.e. a standardised integrated scoring range (0-5 or 0-10) would be a recommendation for each of the various assessment methods. This would also enable the use of one or more than one indices.

8.4.2 Combine the use of functional and biological assessment tools

The advantage of having tools for both functional and biological assessment of wetlands has been discussed (Chapter 3). The two approaches are designed for different purposes, but can be supportive of one another, and can provide validation of the other's indicators and variables (US EPA 1998f).

In South Africa, the tool recently developed for functional assessment of wetlands, WETLAND-ASSESS (Kotze et al. 2004), is still in the trial phase. According to the authors, the method is suited to use in wetland Reserve Determination process. It does not, however, provide sufficient focus on the determination of ecological character to establish a sound basis for determining the ecological status and importance and sensitivity of the wetland (PES, EIS and Ecological Category) that the Reserve Determination process requires (DWAF 1999). As it is focussed on function rather than biology, it provides no information on the attributes of biota and biotic communities occupying the wetland, and is thus also limited in its ability to provide information on the habitat and water regime requirements of particular biota.

The **second recommendation** is that the value of both functional and biological assessment be recognised by the use of a combined approach which incorporates both and requires either (or both) a habitat assessment, and/or measurements of basic physical and chemical variables. This is not a new idea: in the US, the Index of Plant Community Integrity (IPCI) was developed by DeKeyser et al. (2003) with the intention of combining a biological assessment with the HGM functional assessment method of Smith et al. (1995). The IPCI is described in Section 6.2.2.

The integrated protocol would comprise a functional and a biotic assessment module. It is recommended that the former be represented by WETLAND-ASSESS (Kotze et al. 2004) and that in keeping with this, the HGM classification incorporated in WETLAND-ASSESS be used in determining palustrine wetland types. In Minnesota, the Pollution Control Agency developed two bioassessment methods: an IBI for plants and an IBI for invertebrates. These are used in combination with measured physical variables (Gernes & Helgen 2001, Section 6.3).

8.4.3 Adopt a multivariate approach to bioassessment

In a survey of various biota in 53 wetlands in the Carnarvon Basin, Halse et al. (2000) reported that sites classified according to i) plants ii) invertebrates and iii) waterbirds all provided different results. These authors suggested that until a whole index of biotic integrity of wetlands could be devised, wetland assessment should be based on as many biotic variables as possible.

As discussed in Chapter 6, functional indicators provide a picture of how different levels of human interference affect wetland processes and function, while different biological indicators can be used to assess or monitor aspects of overall wetland quality and change in response to specific human activities. Different biotic indicators different provide clues to the numerous aspects of the ecological character of a wetland and to the sources and extent of impairment (Table 6.3). Different indicators are useful for different applications.

It is recommended that a number of biological variables are used in assessment of wetland condition. Each variable should be assessed using a separate method with its own scoring criteria. The scoring ranges, and the condition classes that relate to, should however be common to all the final output of all methods (e.g. a final score of 0-5, with each number in that range being associated with a description of ecosystem condition). This provides the option of consolidating these indices into one composite, mutivariate index score (or graphic).

The biotic assemblages considered for index development in this report are: plants; algae; invertebrates; fish; amphibians; and birds (Chapter 6). It would be possible to develop assessment protocols for any one of these variables, following the US EPA method for developing an Index of Biological Integrity (IBI) presented in Appendix G. This is, however considered an unlikely outcome! The ideal option to pursue to would be a field survey with a multidisciplinary team, to study the different components of the biota of a single wetland type, to identify group attributes and indicator taxa and to develop metrics based on these, and to make a decision as to which assemblage/s to develop further assessment methods/IBIs for.

The US Geological Survey took this approach when developing a method to evaluate the success of wetland rehabilitation activities in depressional freshwater wetlands in eastern Maryland. A multidisciplinary team was commissioned to do research into a biological assessment method. This group of researchers took measurements of hydrology, soil, water chemistry, vascular plants, macroinvertebrates, amphibians, birds and mammals in these wetlands, to identify reliable indicators of wetland condition. Attributes of each group were tested, and results analysed to identify metrics that showed clear, empirical change in value across a human disturbance gradient. This information will be used in developing IBIs for one or more components (US EPA 1998h). Unfortunately, resources in South African agencies are unlikely to support such a protracted and costly investigative approach.

In this light, the **third recommendation** is that initially, the DWAF RQS should, in Phase 2 of this study, prioritise index development as follows, on the basis of the results of this study:

1. Plants;
2. Macroinvertebrates;
3. Fish (chiefly in floodplain wetlands and lakes);
4. Algae and diatoms.

These are prioritised firstly on the basis both of what is known of these biota in wetland and other aquatic ecosystems of South Africa, and secondly on the frequency and reported effectiveness of their use in wetland assessment methods elsewhere in the world.

As IBIs for birds and amphibians are not yet in extensive use, it is suggested that these two biotic assemblages should rather be incorporated into wetland assessment in a qualitative, descriptive fashion. The importance of birds in indicating landscape-scale change is not underestimated. Conservation agencies could possibly take responsibility for the development of standard indices for these taxa.

i. Plant-based index

Consultation with South African wetland specialists reveals a definite preference for a plant-based index. Vegetation is the best known component of the South African wetland biota (Marneweck and Walters, pers.comm. 2004), and the opinion is that elements of the vegetation would provide the most useful information regarding wetland ecological character (e.g. Day, Lindley, Marneweck, Walters, pers.comm. 2004). Vegetation is considered a superior indicator of both condition and change (in response to natural or non-natural stressors) in ecosystems which display high morphological and hydrological variation both in space and time.

The method in development by MWP is a rapid assessment protocol based on wetland vegetation, and has to some extent borrowed ideas from the Riparian Vegetation Index developed by Kemper (1999) for assessment of riparian vegetation (Walters pers. comm. 2004). The method interacts with the HGM classification within WETLAND-ASSESS. According to Walters (pers.comm. 2004) it is not likely at present that the method would be further developed in such a way as to provide a legally-defensible index of condition for use in the Reserve Determination process.

The wetland delineation process (DWAF 2003) uses vegetation as an indicator of wetland condition, based on a broad plant classification developed by Reed (1988, Table 7.4). Lists of indicator plant species providing a basic indication of tolerance to wet soil have been developed for certain plant types (Appendix F) and additional lists along similar lines could be developed for the full range of plants found in different wetlands (Marneweck pers.comm 2004). This could represent a first-generation bioassessment method using plants, however it would be lacking in scoring mechanisms, and these would have to be devised and incorporated. The method operates at the level of species which is not ideal for a rapid approach. However, if the water requirements of plants were to be indicated in this method this would equip the Reserve Determination process with additional, and potentially legally-defensible, information on plant response to altered wetland hydrology, and this represents a powerful combination of elements within one method.

Another option for the use of plants would be to adopt the IBI approach (e.g. US EPA 1998e, Appendix G) in index development.

The **fourth recommendation** is that the extensive existing knowledge and development in the field of wetland plant ecology be applied to (i) the further development of a flexible, generic wetland Vegetation / Plant Index for assessment of wetland condition, and (ii) the gradual modification of this index, such that the indicators used are appropriate both to individual wetland types/subtypes and to ecoregional settings. It is recommended that this process be commenced as soon as possible, possibly commencing with an initial specialist workshop.

Macroinvertebrate-based index

Although there was little support forthcoming in SA for a macroinvertebrate index for wetlands, it is likely that this was in part related to the lack of specialist knowledge and experience in this field. From discussions with wetlanders in SA, and literature review, it seems that little research or practical work has been done on the invertebrates of our palustrine wetlands, and little is known of their occurrence, distribution, habitat preferences, and variability over time and space.

This dearth of information is in itself sufficient justification for the initiation of invertebrate monitoring in wetlands (e.g. Helgen 2002). However, as the objective is to consider a macroinvertebrate index rather than inventory, the justification must be based on reports of the effectiveness of such an index elsewhere. The **fifth recommendation** of this study, to develop an invertebrate index for South African wetlands, is thus based on the relatively wide acceptance that such methods continue to achieve in the United States and in Australia, as described in Chapter 6; and on the author's experience of the use of macroinvertebrates as broad-level indicators of system condition in a range of temporary streams in the Eastern Cape (Uys 1998).

The current lack of knowledge regarding wetland invertebrates could hinder the enactment on obstruction in enacting this recommendation. However, the review suggests that the invertebrates which occupy wetlands are the same taxa as those collected in rivers. As we have many individuals trained in family-level identification of aquatic invertebrates in this country, this gap in our knowledge base could be relatively quickly addressed through directed field studies.

There are two options for the development of an invertebrate index. The first is to develop a macroinvertebrate Index of Biotic Integrity, along similar lines to those developed within the US EPA Biological Assessment Wetland Working Group (BAWWG) initiative (as described in Chapter 6). The second is to develop a sensitivity-based method similar to that of the

Australian SWAMPS approach developed by Chessman et al. (2002) and the SASS5 index in current use in the d in monitoring of South African rivers.

The US EPA method for the development of an IBI for any biotic variable is reproduced in Appendix F. The advantage of the IBI approach is that in the development process, the individual attributes and metrics are tested and evaluated such that those finally included show well-established and documented relationships with different ecosystem variables and a predictable change in value along a gradient of human disturbance. This process ensures that the method is tailored to provide valid indication of particular human-induced changes in a wetland system (or the catchment which affects it). In an assessment exercise, each metric score can then be interpreted relative to either the human disturbance gradient, or to other physical/chemical variables with which it has shown a strong correlation. The method thus provides both broad (e.g. Total IBI score), and more focussed (e.g. individual metric score), levels of information, and represents a powerful tool in assessment.

Note that if the IBI approach were to be followed, it may be wise to field-test metrics already in use in the US, rather than to develop new and independent metrics.

The disadvantages of the IBI method are that the metrics are relatively complex for a rapid bioassessment approach, and the scoring and determination of condition category requires is not straightforward. Indices which are complex to use in the field are advocated against by wetlanders (Marneweck, pers.comm.). The development time for an IBI for a single wetland type is estimated at several months for each habitat type within the wetland; and once the method is developed, the field work is estimated at one hour per site.

The development of a sensitivity index, along similar lines to SWAMPS, could be a simpler option to pursue. However, SWAMPS was developed for use in coastal floodplain wetlands, and its applicability in different wetland types has not been demonstrated. In addition, ‘dominant (wetland) habitat types’ are sampled using sweep nets, which suggests that the wetlands sampled were all inundated to a depth greater than 20cm. No sampling methods are offered in SWAMPS for wetlands in which surface water is less shallow. SWAMPS is also based on an invertebrate index developed by Chessman et al. (1997) for use in eastern Australian rivers. The assumption that a method designed for use in flowing habitats is transferable to a largely lotic or seasonally-wet ecosystem is a source of some concern in the field (e.g. Butcher 2003). Testing of the method is advised, if this option is chosen.

The decision as to which approach to follow in development of a macroinvertebrate index should be informed by further discussion between members of the Project Team, Steering Committee, and other wetland specialists. Ideally, as already mentioned, a field survey should be undertaken, in which versions of each approach are trialled in one appropriate palustrine wetland type. The skill and effort levels required for sampling, sorting, identification, scoring, and interpretation of the data could be recorded and compared. Different sampling methods could be field-tested. This exercise would be considered a first, coarse-level estimate of the applicability and logistics of the method, and the likely usefulness of such a method in indicating wetland condition.

iii. Fish index

There is surprisingly little information on the use of fish in the assessment of wetland condition, as is reported in Section 6.4. However, the knowledge-base regarding the autecology of fish in South African waters is reasonably well-developed, and fish have been in use in biomonitoring of rivers for over a decade.

The **sixth recommendation** of this report is that a fish Index of Biological Integrity, along similar lines to that used in rivers in South Africa (Kleynhans 1999), be adapted for use in lacustrine systems and in wetlands with direct connectivity to river systems, including the following palustrine wetland types (from Kotze et al. 2004): floodplain; valley bottom with a channel, valley bottom without a channel. The specific rationale for the inclusion of a fish index (despite the paucity of these methods overseas) is that the linking of fish response to differing hydrological variables (depth, duration of inundation, etc) is a field in which South Africa has significant expertise in the form of Dr Neels Kleynhans (DWAF: RQS) and others.

The inclusion of a fish index and the simultaneous provision of fish-health related information where relevant in wetland Reserve Determinations would add enormous value in providing ecologically-meaningful recommendations for environmental water requirements. Information regarding the linkage between fish health and water regime is of great value in the process of in the setting of PES and EIS categories, in assessing environmental water requirements, and in determining biotic response to different water regime scenarios (within the Ecological Reserve Determination process). This applies particularly to floodplain systems. There are a are a number of large floodplain systems in South Africa which are important strategically, and are common targets of streamflow reduction activities (SRAs), and thus likely to require Reserve Determinations (Kleynhans pers.comm. 2004). These systems also form the basis of important fisheries (and thus have links to sustainable livelihoods). Fish are likely to be one of the best indicators of biological integrity in these systems.

iv) Algal and diatom-based indices

The support for the development of indices based on algae and/or diatoms comes is a great deal less enthusiastic than that for the better known biota of aquatic ecosystems. Joska (pers.comm. 2004) comments that despite the fact that algae are excellent indicators of water quality and water quality change, the development of an index is not considered justified in South Africa as insufficient attention is being paid to this group in the research field, and there are insufficient individuals trained in algal taxonomy. However, she strongly recommends that algae be incorporated in the wetland assessment process, at least at a qualitative, descriptive level. Joska comments that for this to be practically implementable, a colour photographic guide to the algae of South African waters is required. Such a text is already available and reportedly in wide use in Australia. The **seventh recommendation** is that, in the short-term, algae be incorporated into the assessment process, at a purely descriptive and field-based level, and that a colour photographic guide to the algae of aquatic ecosystems in SA be commissioned. Joska (pers.comm. 2004) has sufficient wherewithal to produce such a guide.

Diatoms are considered to be the least well-known of the biological indicators, and as such may be prioritised unfairly. However, it is clear that a working understanding of the taxonomy and autecology of diatoms resides in the hands of a few, and it is likely to be several years before SA is ready to consider this group as a major indicator of aquatic ecosystem condition for use in management applications. One great advantage of diatoms is in their potential as indicators of historic wetland spatial extent and condition. The eighth and final recommendation of this report is thus that DWAF, in collaboration with WRC and potentially other partners, invest resources in the further development of a diatom index for the assessment of historic wetland boundaries and present wetland condition. This would be a progressive and far-sighted investment. It is recommended that the bulk of development should remain in the hands of the present research team at the University of Potchefstroom, who have a number of students already working in this field.

Over the longer term, it is recommended that resources be allocated by the diverse agencies, projects and programmes interfacing with wetland research in SA, to the expansion of the field of research and training in the ecology and taxonomy of algae and diatoms, such that these two groups can, within five years, be considered for use as indicators of aquatic ecosystem condition.

8.4.4 Encourage further research on the development of qualitative assessment methods using birds and amphibians

While waterbirds and amphibians have not been extensively used in wetland assessment, it is expected that amphibians represent the best opportunity of assessing condition of larger landscapes in which wetlands play a role; and birds are important indicators of the connectivity between wetlands at large spatial scales. The **ninth recommendation** is that DWAF:RQS plays a role in encouraging directed research into both these groups of biota and their potential as qualitative indicators of the larger scale issues relating to wetlands within landscapes, and across continents. If sufficient data were collected over time from unimpacted wetlands in order to establish a frog-species reference condition for different wetland types, then a number of approaches could be integrated into a wetland assessment method. These approaches include the use of audio recordings of inundated wetlands, and specialist use of "call site utilisation", and assessment of morphological changes in the tadpoles of certain species to provide an indication of the water quality status of certain wetlands. The potential for the development of a broad amphibian index of wetland condition should be explored further, in collaboration with amphibian and wetland specialists.

8.5 SUMMARY AND CONCLUSION

This report has provided a Situation Analysis of wetland assessment approaches and methods in use in different parts of the world and in South Africa. A conceptual distinction has been made between the inventorising, assessment and monitoring of wetland ecosystems. Linkages have been made between *functional assessment* approaches, which were initially designed to assess likely impacts of developments on wetland process and function, and *bioassessment* approaches which aim to evaluate the biological integrity and overall ecological character of a wetland. The importance of bearing in mind the relationship between the biota of a wetland and the water regime has been emphasized, with particular reference to the development of one or more bioassessment protocols for incorporation into the DWAF Wetland Reserve Determination process. Aspects of the latter process, which require addressing have been highlighted in this report. The final recommendations have taken account the likelihood that assessment of wetland condition will have to take different forms in the array of wetland types and geographic regions in SA, as they have in the US.

The first recommendation is for the development of a framework for wetland inventory, assessment and monitoring in SA, to form the basis of a future wetland monitoring programme. It is suggested that a combination of functional and biological assessment approaches be used in future wetland assessment, to provide both wide-ranging information on structure and function, and crucial information on ecology and biodiversity of our wetland systems. The recommendation that bioassessment protocols (possibly in the form of Indices of Biological Integrity) be developed initially for plants, invertebrates and fish of floodplain (and other river-linked) wetlands, and over the longer term for algae and diatoms, is considered feasible within the timeframes of this project. The development of plant assessment protocols should rest chiefly in the hands of those who already have such methods in development, however these teams should be informed by DWAF's management requirements. The development of invertebrate and fish indices for use in wetlands should be attended to in Phase 2 of this project.

It is intended that this report should serve as an introduction to a process of formulating approaches and methods for use in wetland assessment in South Africa. It is hoped that the lessons learnt from other countries in the process will be recognised and absorbed by wetland scientists and resource managers in SA, to prevent having to repeat costly learning exercises, and to ensure that spending in this regard is focussed and effective. The nurturance and strengthening of the cooperative links that already exist between different government agencies and government or private programmes focussed on wetlands is strongly encouraged, in the further development of wetland assessment in SA.

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APPENDIX A:
WETLAND CLASSIFICATION SYSTEM

Definitions of the three wetland types addressed in the preliminary Wetland Reserve Determination Method (DWAF 1999, Appendix W1

Senior Author(s):John Dini, Geoff Cowan, Peter Goodman.

Lacustrine System

Definition

The Lacustrine System includes wetlands possessing **all** of the following characteristics:

- situated in a topographic depression or a dammed river channel;
- total area greater than 8 ha; and
- surface area coverage by mosses, lichens, trees, shrubs or persistent emergents of less than 30%.

Similar wetlands of less than 8 ha are also included in the Lacustrine System if they possess **at least one** of the following characteristics:

- water depth in the deepest part of the basin exceeds 2 m at low water; or
- a wave-formed or bedrock feature makes up all or part of the shoreline boundary
- If a wetland qualifies as Lacustrine under the above criteria, but additionally possesses **all** of the following characteristics, then it is classified within the Endorheic System:
- roughly circular to oval in shape, sometimes kidney-shaped or lobed;
- flat basin floor;
- less than 3 m deep when fully inundated; and
- closed drainage (lacking any outlet).

Description

The Lacustrine System includes permanently flooded lakes and dams. Lacustrine waters may be tidal or non-tidal, but ocean-derived salinity is always less than 0,5 g/l. Typically, there are extensive areas of deep water, and there may be considerable wave action. Islands of Palustrine wetlands may lie within the boundaries of the Lacustrine System.

Boundaries

The Lacustrine System is bounded by:

- non-wetland;
- wetland dominated by mosses, lichens, trees, shrubs or persistent emergents; or
- a Riverine wetland entering or leaving the wetland.

Subsystems

Limnetic: all habitats lying at a depth of greater than 2 m below low water within the Lacustrine System. Many small Lacustrine ecosystems have no Limnetic Subsystem.

Littoral: all wetland habitats in the Lacustrine System extending from the shoreward boundary of the system to a depth of 2 m below low water, or to the maximum extent of non-persistent emergents, if these grow below depths of 2 m.

Classes

Water Surface, Non-vegetated, Aquatic Bed, Emergent

Palustrine System

Definition

The Palustrine System includes:

- all non-tidal wetlands dominated by trees, shrubs, persistent emergents, mosses or lichens (greater than 30% surface area coverage);
- tidal wetlands where salinity due to ocean-derived salts is less than 0,5 g/l; and
- wetland habitats lacking the vegetation listed in the first bullet, but with all of the following characteristics:
    - area less than 8 ha;
    - water depth in the deepest part of the basin less than 2 m at low water;
    - lacking active wave-formed or bedrock shoreline features; and
    - salinity due to ocean-derived salts less than 0,5 g/l

If a wetland qualifies as Palustrine under the above criteria, but additionally possesses **all** of the following characteristics, then it is classified within the Endorheic System:

- roughly circular to oval in shape, sometimes kidney-shaped or lobed;
- flat basin floor;
- less than 3 m deep when fully inundated; and
- closed drainage (lacking any outlet).

Description

The Palustrine System groups together vegetated wetlands traditionally called marshes, swamps, bogs, fens and vleis, which are found throughout South Africa. Palustrine wetlands may be situated shoreward of river channels, lakes or estuaries; on river floodplains; in isolated catchments; or on slopes. They may also occur as islands in lakes or rivers. The erosive forces of wind and water are of minor importance except during severe floods.

Boundaries

The Palustrine System is bounded by:

- non-wetland; or
- Marine, Estuarine, Lacustrine or Riverine Systems.

Subsystems

Flat: wetland habitats occurring on areas of comparatively level land (slope less than 1%) with little or no relief, but not directly associated with either a valley bottom or floodplain feature

Slope: wetland habitats occurring on areas with a gradient of greater than 1%, but not directly associated with either a valley bottom or floodplain feature. Usually slopes will be found along the topographical continuum between the plateau or crest and the valley bottom.

Valley bottom: wetland habitats occupying the bottom of the topographical sequence in Figure 2. They are not necessarily associated with a river channel.

Floodplain: wetland habitats falling within areas which are:

- adjacent to a well-defined river channel;
- built of sediments during the present regimen of the stream; and
- covered with water when the river overflows its banks during a 1-in-10 year magnitude flood event.

Distinct morphological features, such as levees and oxbow lakes may be present and the substrate is dominated by alluvial or hydric soils.

Classes

Water Surface, Non-vegetated, Aquatic Bed, Emergent, Scrub-Shrub, Forested

Endorheic System

<u>Definition</u>

The Endorheic System comprises wetlands that would otherwise be classified as Palustrine or Lacustrine, but which possess **all** of the following additional characteristics:

- circular to oval in shape, sometimes kidney-shaped or lobed;
- flat basin floor;
- less than 3 m deep when fully inundated; and
- closed drainage (lacking any outlet).

APPENDIX B: FRAMEWORK FOR DESIGNING A WETLAND INVENTORY ASSESSMENT AND MONITORING SYSTEM (WIAMS)

From Ramakrishna (2002)

Step 1. Establish the purpose of gathering the information.
• Is it for assessing or evaluating the ecological features of the wetland?
• Is it for identification of the nature of a problem or impact or adverse change in the wetland?
• Is it for assessing values to the functions of the wetlands?
• Is it for evaluating the importance of the wetlands based on current status and threats?
The end result of this objective is to prioritise the list of wetland in terms of their Importance

Step 2: Gather information
Inventorise or have a checklist of all the wetland sites both natural and man made:
• State location, size, physical, chemical and biological features
• State human activities, threats, protection and management status
• State the benefits provided by the wetland

Step 3: Uses of the assessment
• The evaluation of wetlands proposed for development
• Evaluation of impact for planning purposes
• Evaluation of wetland restoration potential for conservation purposes
• Determining wildlife habitat potential
• Evaluation of impacts to wetlands from development
• Determine the value of wetlands where changes in land management are proposed to occur

Step 4: Choose an appropriate method
Choose a method that is appropriate for a specific assessment need. There are 4 general types of approaches:
I. Desk study assessment
These are techniques which describe the aerial extent and or types of wetlands. This includes aerial photographs, topographical maps, watershed based GIS data,
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remote sensing data, wetland classification based on soil or substrate type or vegetation community.
II. Rapid assessment protocols
These are mostly low-cost techniques in which the data necessary to perfom the assessment may be gather in a short period of time. The results are likely to involve a large extent of subjective judgement.
III. Data-driven assessment methods
These are data based analytical (quantitative) methods that are usually expensive to develop and time consuming and often model based, but provide a high degree of reproducibility. The results often have predictive value.
IV. Bio-indicators/Indices of Biotic Integrity
Single criterion evaluation – e.g. bird species richness may be used or multicriteria evaluation techniques have been used to assess the ecological importance of sites. These may include biological criteria such as species richness, species diversity, habitat diversity, presence of rare, endangered and endemic species.

Step 5: Analysis of the Results
Evaluation Phase
Benefits that wetlands provide
I. Direct uses (also called goods)
• Fisheries
• Agriculture
• Energy
II. Functions (also called services)
• Flood control
• Shoreline stabilisation
• Prevention of salt water intrusion
• Water transport
• Sediment/nutrient retention
• Toxicant removal
• Microclimate stabilisation
• Education
• Research
• Tourism
• Recreation
III. Attributes
• Biological diversity; gene bank
• Unique cultural heritage
• Life cycle – migration routes, nursery grounds
• Global carbon sink
• Prevention of development of acid sulphate soils
These criteria are ranked in relation to each other (direct uses, functions and attributes). Degree of threat is also ranked according to the type and degree of threat operating on them. The output is a listing of wetland sites prioritised for their importance.

Step 6: Report the results/information
Report results and application
• For decision making
• For management purposes
• State whether or not objective has been achieved
• State contain recommendations for management action
• State whether further information is required
• Evaluation of methods used

Step 7: Sound management of wetlands
• What type of management required for a particular wetland
• What resources to safeguard
• What monitoring protocols to adopt and use
• Feedback to management plan
• Management actions taken to minimise negative impacts identified through monitoring

APPENDIX C: METRICS USED BY THE USA EPA IN AQUATIC SYSTEMS

(from US EPA 1998a-f)

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Potential metrics for various taxa, developed predominantly for rivers and lakes, not palustrine wetlands. The efficacy of the metrics needs to be tested in South African wetlands.

Algae
• Trophic state
• Number of taxa
• % dominance
• Indicator taxa, ecological categories and tolerance indices
Primary production
Periphyton species assemblage/composition
Sediment diatoms
Periphyton

Submerged macrophytes
• % cover of biomass in available habitat colonised
• % cover, biomass in vegetated areas
• Number of taxa
• % cover, biomass of dominant species
• Number of exotic species
• % cover, biomass of exotics

Macroinvertebrates
• Number of taxa
• Shannon-Weiner diversity
• Mean number of individuals per taxon
• % contribution of dominant taxon
• % intolerant species
• % oligochaetes
• ETO Ephemeroptera, Trichoptera and Odonata
• % non-insects
• Crustacean and mollusc taxa
• % crustacean and mollusca
• % suspension feeders
• % shredders
• Abundance excluding chironomids and tubificids
• Number of samples with no organisms present
Work done by R. Butcher unpublished suggests that the number of macroinvertebrate taxa may not be a good indicator to separate between the four freshwater wetland categories.

Zooplankton
• % large Daphnia (>1mm)
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• number of taxa
• % dominance
• size structure (% of large animals or % of small animals)
• Trophic structure metrics: number of trophic links; complexity measures; % large predators; number of predator species.

Fish

Species richness and composition
- Number of taxa
- Number of intolerant species
- % tolerant individuals
- % dominance by one species

Trophic composition
- number of piscivore species
- % omnivores
- % invertivores

Reproduction composition
- number of lithophilic spawning species

Abundance
- Total individuals

Fish health
- % individuals with anomalies

APPENDIX D.
RESERVE DETERMINATION METHODS FOR PANS

By Gary Marneweck

There is therefore concern over the applicability of some of the means of determining PESC and ERC, which were developed primarily for floodplain wetlands (in the generic protocol for wetlands, DWAF 1999). The applicability concerns pans in particular, but also other palustrine wetlands. **Indications are that the protocol as it stands cannot be used directly for pans or even other subtypes of palustrine wetlands, and will need modification in order to be applicable to these types of systems.**

For pans, most of the attributes (which were developed for floodplain wetlands and adapted from Kleynhans, 1999) for determining PESC and EISC are not applicable. Many pans are also not closed or endorheic as previously believed. There are a number of additional characteristics of pans that need to be addressed when scoring each attribute. These are:

Determination of Present Ecological State Category (PESC) and application to pans

The PESC for rivers and wetlands is determined on the basis of a number of attributes. Each is described below, and its relevance to pan systems is discussed.

<u>Flow modification:</u> In riverine and wetland systems, this attribute is scored based on the flow through the system. As this is not applicable to most pans, it is more important to consider how flow into the pan has been affected by modification in the pan basin (catchment area), including changes in vegetation and land use.

<u>Permanent inundation:</u> In pans this is not necessarily a negative attribute as may be the case in floodplains. Permanent inundation may be a natural feature of certain types of pans.

<u>Water quality modification:</u> Two issues (i) Water quality in pans should ideally be measured at the highest water level because it deteriorates as concentrations increase through evaporative concentration over time; (ii) Water quality changes in pans is often a natural attribute and this can deteriorate significantly simply due to natural fluctuations from variability in rainfall in the pan catchment.

<u>Sediment load modification:</u> This is not really an attribute applicable to pans although exposure of soils in adjacent agricultural lands could lead to wind transport and deposition in the pan. By the same token, deposited salts may be transported out of the system during the dry periods. Cannot really be used to determine PESC.

<u>Canalisation:</u> The canalisation of endorheic pans is an unlikely activity.

<u>Terrestrial encroachment:</u> Non-permanently inundated pans are inherently hydrologically variable and terrestrial encroachment must be critically assessed since it may be a natural phenomenon based on climatic variability.

<u>Indigenous vegetation removal:</u> Exposed expanses of bare soil need to be critically assessed in terms of water quality and periodicity of exposure or inundation since this may be a natural phenomenon in certain types of pans. Many pans remain bare for extended periods depending on salinities and simply variability in rainfall.

Invasive plant encroachment: In pans it is important that this is assessed in the context of the basin as a whole. For example, *Eucalyptus* species and wattles around Highveld grassland pans may affect the water balance of the pan.

Alien fauna: In the Highveld for example, livestock replace the indigenous bulk grazers that have been lost. Trampling and bulk grazing would have naturally occurred in may of the systems and may play an important role in some of these systems. Overgrazing is obviously an issue of concern that needs to be critically assessed. In permanent pans, the introduction of exotic fish species may also affect the natural processes and trophic structure.

Determination of Ecological Importance and Sensitivity, and applicability to pans

Diversity of habitat types or features: Pans have completely different habitat features that will determine their rating in terms of this attribute compared to floodplains and even other palustrine wetlands. Allan (1985) lists the open water, a submergent zone, an emergent zone and a moist soil vegetation zone as the different cover types (Figure 3) while Rogers *et al.* (1989) show that the open water/littoral zone ratio is an important feature of the diversity of pans. These should all thus be considered when scoring the diversity of habitat types or features in pans. The categories listed for floodplains (DWAF, 1999) are therefore not applicable to pans.

Sensitivity to changes in the natural hydrological regime: Certain types of non-perennial pans may be insensitive to short-term changes in the hydrological regime, but sensitive to long-term changes. The fact that the natural hydrological regime may be variable in some types of pans does not necessarily mean that the pan is not sensitive to changes in the hydrological regime. The change in surface area to volume ratio as the pan draws down, as well as the endorheic hydrology are considered by Rogers *et al.* (1989) as two important features affecting the hydrology of pans, and should therefore be carefully assessed before deciding on a sensitivity rating. In addition, the water requirements of the pan vegetation, particularly in terms of the depth, duration, timing and frequency of water supply need to be taken into account during this assessment. Indicator plant species can be used for this purpose.

Sensitivity to water quality changes: Changes in the concentrations of anions and cations is a natural phenomenon of pans. The concentration of anions and cations will increase as pan water levels drop. However, changes in the anion and cation composition is likely to have a significant effect on pan dynamics, including vegetation composition and hence productivity of the pan.

Flood storage, energy dissipation and particulate/element removal: This category is not really applicable to pans at all and thus cannot be assessed as part of the determination of the Ecological Importance and Sensitivity Category.

Further comment on pans

The relationship between rainfall and water quality as well as hydro-dynamics is one of the key drivers of pan dynamics. This has a direct influence on pan processes and biota.

The concept of health with respect to pans is somewhat questionable. The difficulty arises when one tries to assess health in a system that fluctuates between extremes of desiccation and inundation. Health in these types of systems may have less to do with biota and water quality than with land-use changes within the confines of the basin.

In pans, depth and area need to be established accurately as water losses both through seepage and evaporation need to be defined. More accurate water balance data are, I believe, critical to an understanding of pan dynamics.

Collecting data on the dominant vegetation surrounding the pan is useful for assessing both full supply levels and the EISC, but data collection should not exclude flora in the pan itself, including algae and floating and submerged hyrophytes. These are key resources for supporting waterfowl and invertebrates. Similarly the importance of diatoms and clay mineralogy should also not be overlooked.

APPENDIX E:
AN EXAMPLE OF USING BIOTA IN ENVIRONMENTAL WATER ALLOCATIONS

Case Study of Thomsons Lake, Australia, using the Framework for Environmental Water Allocations for Wetlands *(Reproduced from Davis et al. 2002, references removed)*

Pilot Studies

The framework descibed in Figure 7.2 of the current report was applied to four Australian wetlands (Thomsons Lake, Bool Lagoon, Lower Gwydir Wetlands and Boggomoss Springs) to test or demonstrate its application to different wetland types.

Thomsons Lake

- Step 1. Characterisation of Thomsons Lake
- Step 2. Identify uses, values and threats
- Step 3. Determine management objectives
- Step 4. Describe the relationships between water regime and wetland biota
- Step 5. Determination of the desired water regime
- Step 6. Refine the desired water regime using a conceptual model
- Step 7. Performance indicators
- Step 8. Determine the means of achieving the desired water regime
- Step 9. Set environmental water allocations to achieve the desired water regime
- Steps 10 and 11. Implementation and Monitoring
- Conclusion

Step 1. Characterisation of Thomsons Lake

Site Description

Thomsons Lake is a shallow semi-permanent/ seasonal wetland on the Swan Coastal Plain, approximately 34 km south of Perth. It is part of the East Beeliar chain of wetlands which are expressions of the Jandakot Mound, an unconfined aquifer. Although the dominant source of water for Thomsons Lake is groundwater, there is some surface inflow from Kogolup Lake and from a drain to the south-east of the lake which passes through constructed wetlands. The lake is characterised by both high waterbird abundance and diversity, and areas of sedge vegetation (Directory of Important Wetlands web site).

Hydrological data

The following information regarding the water regime of Thomsons Lake was examined for the purpose of this analysis:

- Rainfall data from the Bureau of Meteorology (1952-1999)
- Perth annual rainfall (1876 to 1985)
- Depth data (m AHD) from the Water Corporation (1952-1999)

- Duration of dry periods (1962-1988) (Balla and Davis, 1993, p.38, Table 3.2)
- Rate of change per day (1974-1990) (Balla and Davis, 1993, p.41, Figure 3.1)
- Bathymetry and vegetation distributions in relation to AHD (Arnold, 1990, p.270)
- Frequency distribution of lake levels (Froend *et al.*, 1993, p.20, Figure 3.6)
- Groundwater abstraction volumes (1979-1985) (Cargeeg, *et al.*, 1987, p.40)

Description of the water regime

Seasonal drying occurred almost annually from the late 1970s to the late 1980s. Both prior to this period and during the 1990s drying did not occur as frequently (Figure 12). Due to the incomplete and highly variable nature of the depth data prior to 1971, it is difficult to draw firm conclusions about the nature of the historic water regime. The relatively high levels which characterised the lake's water regime between 1964 to 1978 may have been a result of excessive inundation caused by clearing of the surrounding *Banksia* woodland for cattle grazing and market gardening.

Rapid changes in water level may have become more common since groundwater abstraction began in 1979, and the frequency at which rapid changes in depths occur may also have increased (Figure 13).

Vegetation

Extensive mats of the aquatic macrophyte *Myriophyllum sp.* occur in the open water. Above this a sedge community of *Baumea articulata*, *Typha orientalis* and *Bolboschoenus caldwelli* occurs. *Typha orientalis* became established during the 1980s and is considered to pose a threat by changing the community composition and the amount of open water (Directory of Important Wetlands web site). Above the level of *T. orientalis*, *Baumea juncea* occurs with a few shrubs, including *Viminaria juncea* and *Acacia saligna*. At higher elevation there is a woodland of *Eucalyptus rudis*, *Melaleuca preissiana* and *Jacksonia furcellata* (Figure 14).

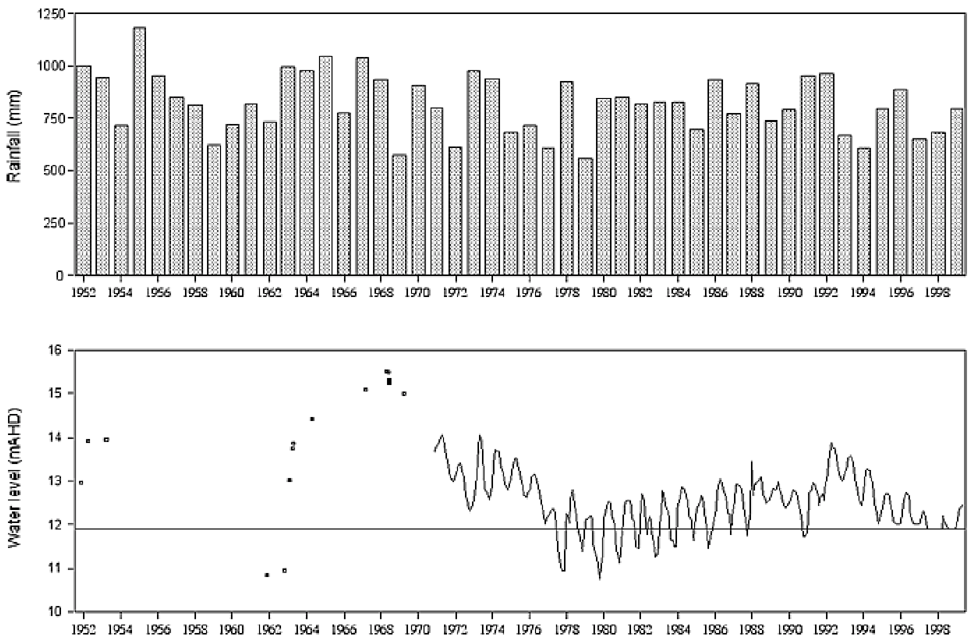

Figure 12. Hydrograph with rainfall data for Thomsons Lake, WA. Data provided by the Water Corporation and the Bureau of Meteorology.

Note: The level of the lake bed is indicated on the hydrograph by a horizontal line. Data prior to 1971 were irregular and so do not show seasonal variation. From the mid-90s bores were not used for measurements, therefore after this time the level of the water table after the lake dries cannot be determined.

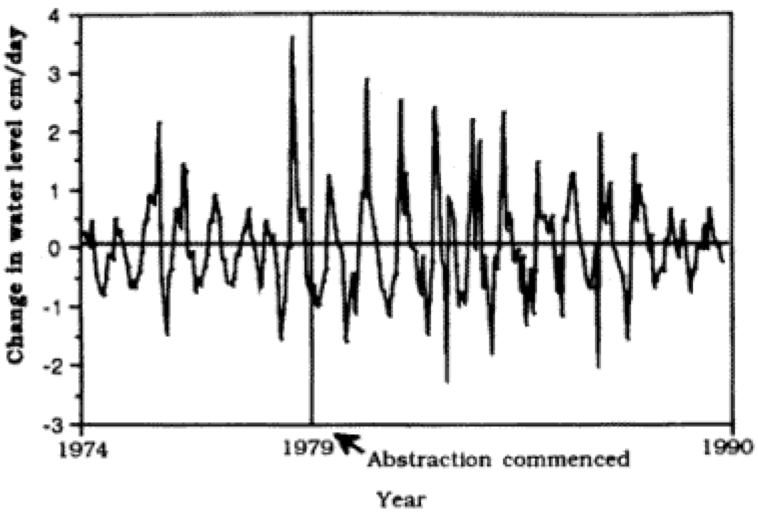

Figure 13. Rates of water level change at Thomsons Lake

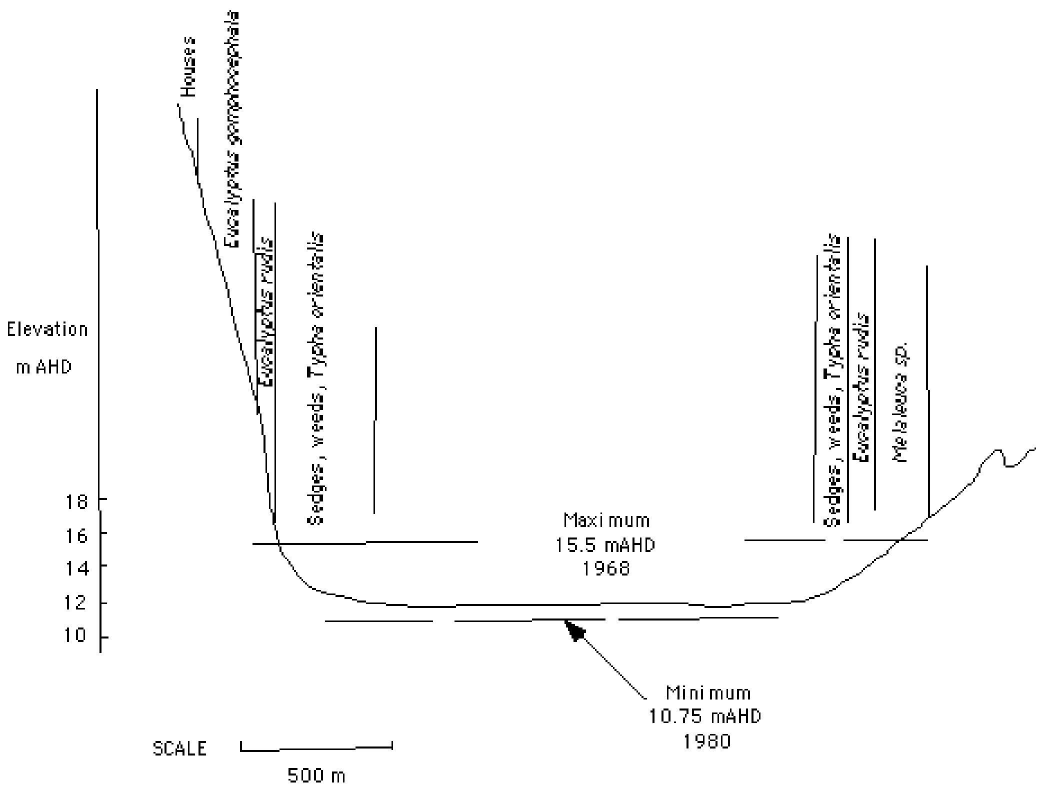

Figure 14. Bathymetry, vegetation and water level records of Thomsons Lake

Vegetation

Extensive mats of the aquatic macrophyte *Myriophyllum sp.* occur in the open water. Above this, but below the usual water mark, a sedge community of *Baumea articulata*, *Typha orientalis* and *Bolboschoenus caldwelli* occurs. *Typha orientalis* became established during the 1980s and is considered to pose a threat by changing the community composition and the amount of open water (Directory of Important Wetlands web site). Above the level of *T. orientalis*, *Baumea juncea* occurs with a few shrubs, including *Viminaria juncea* and *Acacia saligna*. At higher elevation there is a woodland of *Eucalyptus rudis*, *Melaleuca preissiana* and *Jacksonia furcellata* (Figure 14).

Fauna

Fourteen species of migratory waders occur at Thomsons Lake. The threatened Australasian Bittern (*Botaurus poiciloptus*), which is no longer recorded regularly at other Perth wetlands, also occurs (Directory of Important Wetlands web site). Lists of waterbirds can be found at the Directory of Important Wetlands web site and in Crook and Evans (1981). Six species of wetland frogs have been recorded: *Crinia georgiana*, *Crinia insignifera*, *Heleioporus eyrei*, *Limnodynastes dorsalis*, *Litoria moorei* and *Litoria adelaidensis*. The turtle *Chelodina oblonga* has been recorded at the lake. No fish have been recorded (Directory of Important Wetlands web site).

Ecological character

The ecological character of Thomsons Lake was defined as *a shallow, seasonal to semi-permanent, groundwater-fed lake, with fringing sedge vegetation, which supports large numbers of waders in some years*

Step 2. Identify uses, values and threats
Uses

- Extraction of groundwater for domestic water supply for Perth occurs from the Jandakot Mound which also supports Thomsons Lake.
- The lake is used for passive recreation such as walking and birdwatching (Directory of Important Wetlands web site).

Values

Thomsons Lake is a Ramsar site and is of particular importance as a stop-over point for migratory waders. Both waterbird abundance and species diversity are high compared with other wetlands of the Swan Coastal Plain, and it is important locally as a refuge for the threatened Australasian bittern (*Botaurus poiciloptilus*) (Directory of Important Wetlands web site). The importance of an appropriate water regime for waterbirds is both direct, as many have specific habitat needs in terms of water depth, and indirect, as the extensive sedge beds constitute important habitat for some waterbirds. The sedges themselves have particular water regime requirements.

Identified threats to the water regime of Thomsons Lake

Threats to the lake's water regime include both groundwater extraction and excessive inundation caused by clearing and urbanisation (Directory of Important Wetlands web site). The threat of excessive inundation mitigates the effect of groundwater extraction, however the overall effect has been estimated to be a reduction in the groundwater levels on the Jandakot Mound of between 0.10 and 1.10 m. In the future an expected increase in urbanisation on the Mound could possibly result in excessive inundation becoming a problem. Urban drainage may cause short-term water level fluctuations (see Figure 13). A proposal to drain land east of Thomsons Lake for housing development was subject to Environmental Protection Authority restrictions due to concern for the integrity of the lake's water regime.

Wetland vegetation communities of the Swan Coastal Plain are considered to be dynamic, moving up- and down-gradient in response to increased or decreased inundation. However the shallow and essentially flat-bottomed nature of Thomsons Lake (Figure 14) means that a permanent reduction in groundwater levels would pose a threat to its ecological character. A relatively small reduction in groundwater levels would lead to a considerable reduction in the amount of open water.

Qualitative assessments of alterations to water budget elements are listed below (Table 4). Attempts to produce a quantitative water budget have been unsuccessful due to difficulties accessing adequate drainage data. As a result, the extent to which human impacts on the water regime mitigate against each other could not be determined. The overall direction of change in the water regime as a result of human activity (ie. groundwater abstraction vs land clearing) is therefore unclear.

Table 4. Processes which may alter aspects of the water budget of Thomsons Lake.

Water budget element	**Processes at Thomsons Lake which could alter elements of the water budget**	**Nature of alteration**
P Precipitation	Climate change. Rainfall has been below average since the early 1970s	Reduced
Q_i Surface water inflow	Possibly increased from drain from south-east (which is cleared, primarily agricultural land (ANCA, 1996)). Water from this drain enters the wetland after passing through constructed wetlands. These wetlands were constructed to mitigate against increases in nutrient loads. The wetlands are bypassed at times of very high flow. Reduced rainfall (above) may also result in a reduction of surface run-off	Possibly increased
G_i Groundwater inflow	Could be reduced as a result of groundwater extraction	Possibly reduced
E Evaporation/ transpiration	May be affected by climate change and the extent/ health of vegetation	Possibly reduced
Q_o Surface water outflow	n/a	
G_o Groundwater outflow	Dependent upon the level of the groundwater table	

Step 3. Determine management objectives

As a Ramsar wetland, a suitable general management objective is

To protect against decline in the ecological character of the site.

A specific management objective, based on the identified values, is

To protect the site's habitat value for migratory waders.

The water regime of Thomsons Lake is currently managed by the Water Corporation to reduce the possible negative impacts of groundwater extraction and drainage of nearby areas for urban development. The existing management objective is

'*to protect the ecological character of the lake and, in particular, its importance as a waterbird habitat'* (EPA, 1990, p.4).

This objective addresses obligations associated with the Ramsar status of the site. Management is aimed at maintaining both the natural seasonality of the water regime, with lower water levels in summer, and the effect of annual rainfall variations on the lake water levels.

Step 4. Describe the relationships between water regime and wetland biota
Water requirements of wetland vegetation

Table 5 lists general qualitative requirements of the wetland plant species of Thomsons Lake. These include adaptations to seasonal drying, and relatively shallow water for the submerged aquatic plant *Myriophyllum sp.*

Table 5. General water regime requirements of vegetation

Type	**Species**	**General Water Regime Requirements**
Aquatic macrophyte	*Myriophyllum sp.*	Requires water that is not excessively deep
Emergent macrophyte	*Bolboschoenus caldwelli*	Requires seasonal drying: becomes established below sedges as the lake dries
Trees	(*Eucalyptus rudis* and *Melaleuca preissiana*)	Degraded by prolonged flooding (>2 years). Where water levels fall over a long period of time, recruitment of young *Melaleuca preissiana* occurs at a lower elevation

The water depth requirements of four emergent macrophyte species are listed below (Table 6). These species generally occur around the fringes of Thomsons Lake (Figure 14). A decrease in water levels such as occurred between 1979 and 1991 may lead to their encroachment towards the centre of the lake. Sedge vegetation in 1987 did in fact cover a greater area of Thomsons Lake than it did in 1963, which was a wetter year (Figure 12). In 1992, a wet year, water levels were very high, and the area occupied by sedges was much reduced in the following year as a consequence. A long-term lowering in water levels would result in less open water habitat and an increase in sedge habitat. However large fluctuations in water levels between wet and dry years may be considered as part of the natural variability of the lake's water regime. These fluctuations result in variability in the area of sedge habitat.

Table 6. Water depth requirements of emergent macrophytes

Species	Range of Depths of Occurrence (Froend *et al.*, 1993)	Mean Annual Depth(Chambers *et al.*, 1995)
Bolboschoenus caldwelli		+0.3 to - 0.2 m
Baumea articulata	Minimum - 1.0m Maximum + 1.0m	+/- 0.4 m
Typha orientalis	Minimum - 1.0m Maximum + 1.0m	+0.1 m to - 0.3 m
Baumea juncea		+0.2 m to -0.3 m

Water Requirements of Wetland Fauna

Vertebrates

Waders require shallow areas and the long-toed stint requires seasonally exposed mud flats. Therefore excessive inundation could potentially be a problem. The large areas of sedges and mud flats may` be critical as habitat for waders; maintaining a suitable water regime for the maintenance of these habitats should meet the requirements of waterbirds. Sudden increases in water level, due to urban drainage, and sudden decreases due to groundwater abstraction may adversely impact frog populations and aquatic invertebrates (Table 7).

When evaluating the habitat requirements of the vertebrates of Thomsons Lake, it is important to consider that the more mobile vertebrates may utilise the entire chain of the Beeliar wetlands. As a whole, this group of wetlands provides a much higher variety of habitats than does Thomsons Lake alone. In particular, nearby Kogolup Lake has a permanent water regime and is used by waterbirds when Thomsons Lake dries up (Rod Smith, Birds Australia, pers. comm.). Mobile vertebrates include waterbirds and the turtle *C. oblonga*. *C. oblonga* can travel overland long distances, although in doing so many are killed on the roads. The predator-proof fence which now surrounds Thomsons Lake may prevent the movement of some non-flying fauna such as turtles.

Table 7. Water regime requirements of wetland vertebrate fauna.

Type	Species	Water regime
Waterbirds	Long-toed Stint (*Calidris subminuta*)	Require exposed mudflats: only appear when these are present (Directory of Australian Wetlands web site)
	Waders (general)	Shallow water levels
	* Australasian bittern (*Botaurus poiciloptilus*) and Little bittern (*Ixobrychus minutus*)	Require tall sedges (Directory of Australian Wetlands web site)* *
	Musk duck (*Biziura lobata*)	Require deep permanent water
	Blue-billed duck (*Oxyura australis*)	Require deep permanent water
Frogs	*Limnodynastes dorsalia*	Survival of embryos within egg masses may require an absence of sudden increases/ decreases in water levels, as the eggs are attached to vegetation and

	and *Litoria adelaidensis*	float on the water surface. The embryos may need to remain on the surface of the water to be both well-oxygenated and wet. Changes in depth which result in either the drying of the egg masses or their inundation (and subsequent de-oxygenation) may be detrimental
	Heleioporus eyrei	Water level increases between March and May may be detrimental to breeding success: this species lays eggs in burrows.
Fish	None present (ANCA, 1996)	
Turtles	*Chelodina oblonga*	This species has two nesting periods (September-October and December-January). May require the presence of water in December/January for the second nesting period, as turtles only eat when open water is present, aestivating when the wetlands dry during summer.
Other reptiles	Insufficient data	
Mammals	Bandicoots	Dense fringing vegetation

(Species List: Crook and Evans, 1981)

* Threatened species

* * See Table 6 for water regime requirements of *Baumea articulata* and *Typha orientalis*, the most abundant tall sedges.

There appear to be few animal species which require permanent water for survival. Exceptions include the musk duck and the blue-billed duck. Musk ducks were recorded in each decade between 1954 to 1979 but are not mentioned in the Directory (Directory of Important Wetlands web site). A loss of this species could be a result of the reduced water levels. The shift from the deeper, permanent water regime which characterised the lake prior to 1978, to the current shallower, seasonal or semi-permanent water regime may have resulted in a reduction in the abundance of diving ducks and an increase in the abundance of waders.

Invertebrates

Adult insects with aquatic larvae require healthy vegetation for resting sites. Some, including adult damselflies, require macrophytes for egg-laying sites. Therefore the maintenance of a water regime which will be suitable for macrophytes is of importance also for the maintenance of invertebrate habitat values. The aquatic invertebrate fauna of the Swan Coastal Plain wetlands are considered to be adapted to seasonal drying. The requirements of aquatic invertebrates should be met if seasonal wetlands do not dry out before December each year, and if rates of wetland drying do not exceed 0.02 m day^{-1}.

Nuisance Species

Increased depth may result in a shift from a system dominated by macrophytes to one dominated by phytoplankton (Balla and Davis, 1993). Cyanobacterial blooms may result, however cyanobacteria may be favoured by the mixing conditions which are typical of relatively shallow depths. Shallow lakes exposed to strong winds conditions (as Thomsons is) often experience diurnal or semi-diurnal cycles of complete mixing and secondary stratification, which favours cyanobacteria over other phytoplankton (Bailey and Hamilton, 1997). The phytoplankton of Thomsons Lake was found to be dominated by cyanobacteria between August and November, 1994 a time when the the lake was relatively deep (Figure 12).

A decrease in water levels may favour *Typha orientalis* while an increase in permanence could lead to the establishment of *Gambusia holbrooki* (Table 8).

Table 8. Nuisance/pest species that may be favoured by changes to the water regime.

Nuisance/pest	Water regime changes favourable
Cyanobacterial blooms	Excessive depth leading to the death of *Myriophyllum sp.* beds (Balla and Davis, 1993).
Typha orientalis	Shallower regime
Introduced fish *Gambusia holbrooki**	Increased permanence

***** Although not recorded at the lake this species colonises most wetlands with a permanent water regime on the Swan Coastal Plain and so there is a high possibility that it will occur in Thomsons Lake if the regime becomes permanent.

Step 5. Determination of the desired water regime

The water regime requirements of the biota of Thomsons Lake and bathymetry and hydrological data were used to develop a conceptual model (Step 6, Figure 11). This was developed to assist in the process of determining a suitable water regime.

Step 6. Refine the desired water regime using a conceptual model
Conceptual model

Scenario 1. Decreased water levels, seasonal water regime (Figure 15).

An overall decrease in water levels would result in a shift of the fringing vegetation communities down-gradient (Froend *et al*., 1993). As the wetland has a relatively flat bed and steep sides, and the sedges and *Typha* occur where the land begins to rise out of the basin (Figure 14), reduction of water levels below a certain point could lead to a spread of the sedge and *Typha* vegetation across the bed of the lake. This would be associated with a loss of habitat for the aquatic *Myriophyllum sp*. (which supports a productive invertebrate fauna) and a loss of seasonally exposed mudflats, which are important for the long-toed stint, a migratory wader (Directory of Important Wetlands web site). Additionally, a reduction in water levels would be associated with recruitment of the wetland trees down-gradient of their present distributions. This is already occurring for *Melaleuca preissiana* at nearby Banganup Lake. If water levels decreased over time, sedges may take over the areas now characterised by open water and mud flats, leading to a loss of habitat for waders. With a further loss, *E. rudis* and *Melaleuca sp.* would take over the bottom of the basin.

Scenario 2. Seasonal or semi-permanent water regime: water levels intermediate between those of scenarios 1 and 3 (Figure 15).

Wader habitat will be optimum if water levels are between approximately 11.5 and 12.5 m AHD (equivalent to depths between 0.3 m below the sediment and 0.7 m above) (Scenario 2, Figure 15). Higher water levels than this would result in a reduction of both wader habitat and the extent of sedge beds (Scenario 3, Figure 15); while lower overall water levels may result in an invasion of the entire lake bed by sedges (Scenario 1, Figure 15).

The long-toed stint (*Calidris subminuta*) occurs at Thomsons Lake when mudflats become exposed in summer/ autumn (Directory of Important Wetlands web site). This would occur only under scenario 2. This migratory species is protected by international agreements. The highest count, recorded in the summer of 1991, represented at least 1% of the probable national population of this species (Directory of Important Wetlands web site).

This was a year when the lake dried. The required habitat of this species, exposed mudflats, only occurs seasonally in relatively dry years. Exposed mudflats would cease to occur if the water regime became permanent, or the wetland became excessively inundated.

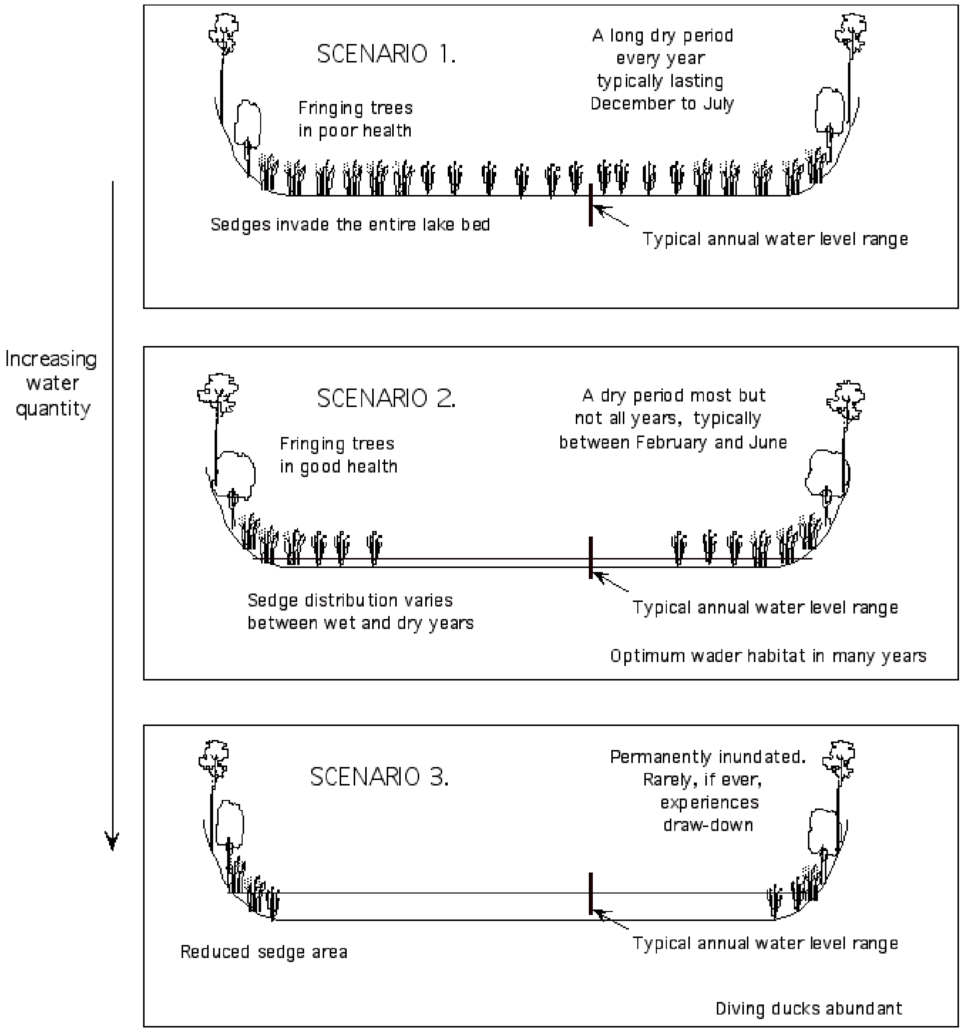

Figure 15. Conceptual modelling: scenarios describing wetland response to changing water regime (Thomsons Lake).

Scenario 3. Deeper water levels, permanent water regime (Figure 15).

An increase in water levels could lead to deaths of *Myriophyllum sp.* beds and possibly deaths of the lower *E. rudis* and *Melaleuca sp.*, although these could re-colonise at a higher gradient (Arnold, 1990; Froend *et al.,* 1993)**.** A severe contraction of the sedge and *Typha* habitat could result (Figure 14). The most abundant waterbirds under this scenario are likely to be ducks and piscivorous birds. Waders would be less abundant, as would the threatened Australasian Bittern, which requires sedge habitat (Table 7). Diversity and abundance of invertebrates may be reduced by the reduction of macrophyte habitat and the establishment of conditions suitable for *Gambusia holbrooki* (Table 8). This may in turn reduce waterbird abundance. Deeper water levels may satisfy a possible alternative management objective of providing landscape amenity in the form of year-round open water views. However, if the increase in water level were to be associated with algal blooms as a result of a shift from a macrophyte-dominated system to a phytoplankton-dominated system, the amenity value would be reduced.

Scenario 4. Rapid water level fluctuations due to influence of drainage water.

Rapid water level fluctuations may negatively impact the breeding success of the frogs *Limnodynastes dorsalia* and *Litoria adelaidensis* (details Table 7). Some aquatic insects may not be able to complete their life cycles before the lake dries. Waterbirds such as coots, with nests attached to vegetation may be negatively impacted by rapid changes in water levels.

Desired water regime

The water regime of Scenario 2 satisfies the management objectives best. Inter-annual rainfall variation will mean that Scenarios 1 and 3 occur after successions of very wet or dry years. Scenario 4 may occur as a result of increased urbanisation.

Step 7. Performance indicators

Performance indicators could be defined in terms of relative areas of various habitats. Inter-annual variation would have to be allowed for; for example, large-scale reduction in the area of *Typha* in wet years, and increases in dry years. This variability due to climate could be accommodated by wording the performance indicators in a similar manner to the water level criteria:

'The area of sedge vegetation is not to increase/decrease by more than a determined percentage for a certain number of years per decade, or for more than a certain number of consecutive years'.

Additional performance indicators could be based on the breeding success of waterbird and frog species identified in the conceptual model as threatened by excessive water level fluctuations (Scenario 4).

Step 8. Determine the means of achieving the desired water regime

The desired water regime could be achieved by setting environmental water requirements in terms of water levels, allowing for inter-annual variation due to climate variability. Human impacts such as groundwater extraction, urban development and drainage could be modified in order to meet these requirements. This has been the approach used in the management of Thomsons Lake's water regime (WAWA, 1992).

Step 9. Set environmental water allocations to achieve the desired water regime

Existing criteria were first examined to determine their sense not clear in this context.

Existing criteria for the management of the water regime of Thomsons Lake

WAWA's operational criteria for the management of abstraction in terms of the water level of Thomsons Lake are:

'groundwater abstraction must not result in water levels falling between 10.8 and 11.3 m AHD more than once in any ten year period'

(WAWA, 1992, Section 3.5.3).

This criterion is compatible with scenario 2 of the conceptual model (Step 5).

Table 9. Relationship between criteria water levels in mAHD and water depths.

Water level in m AHD	Approximate depth of water in the middle of the lake
10.8	1.0 m below sediment surface of the lake bed
11.3	0.5 m below sediment surface of the lake bed
11.8	Water at the sediment surface of the lake bed. Lake bed saturated but not inundated.

Suitability of the water level criteria (WAWA, 1992)

The minimum water level criteria for management is 10.8 m AHD (WAWA, 1992). This equates to the minimum level required for the health of emergent macrophytes. The point at which the water table is approximately at the surface of most of the lake bed occurs at 11.7 m AHD (Table 9) (Arnold 1990, p.269 Figure 9.15). When the water depth is at 10.8 m AHD, the water table is approximately 1.0 m below the ground level. According to Townley *et al*. (1993) this is the point at which the capillary rise of water can no longer reach the roots of emergent macrophytes (Table 10). *Baumea articulata* and *Typha orientalis*, the most abundant emergent macrophytes at Thomsons Lake, occur in the zone where the level of the water table varies between 1.0 m below and 1.0 m above ground level (Froend *et al.,* 1993). The minimum water level criteria of WAWA (1992) should adequately protect the extensive sedge areas (Table 10). The other criteria, that the level not fall between 10.8 and 11.3 m AHD more than once every 10 years due to abstraction (WAWA, 1992), results in the water table not falling below 0.5 m of the sediment surface more than once every 10 years. This should also protect the health of the emergent vegetation, as the optimum water level for *B. articulata* and *T. orientalis* is + / - 0.1 m above the lake bed Table 10). This should in turn ensure the protection of fauna habitat, including waders and invertebrates.

Short-term water level fluctuations

The issue of increased short term water level fluctuations is not covered by WAWA's (1992) criterion. This has the potential to negatively impact invertebrate, frog and waterbird populations (Scenario 4, conceptual model). A maximum rate of change of 0.02 $m.day^{-1}$ has been included as a criterion for wetlands of the Gnangara Mound, on the basis of the requirements of aquatic invertebrate communities. This criterion could be incorporated into the general criteria for the management of Thomsons Lake.

Table 10. Water regime criteria in relationship to depth and water regime requirements of wetland vegetation and fauna.

Criteria (WAWA, 1992) Water levels in m AHD	**Effect of criteria in terms of the lake's water regime.**	**Match with water requirements of biota**
WAWA (1992): Groundwater abstraction must never result in water levels falling below 10.8 m AHD. (Water levels are artificially maintained to meet this criteria).	The water table should never fall more than 1 m below the lake surface*.	Townley *et al*., (1993): This is the point at which emergent macrophytes can no longer access water. Matches the lowest water level that *Baumea articulata* and *Typha orientalis* can survive.
WAWA (1992) Groundwater abstraction must not result in water levels falling between 10.8 and 11.3 m AHD more than once every 10 years.	The water table should not fall in the range of 0.5 to 1.0m below the surface of the lake bed more than once every 10 years**.	Preserves the health of sedge beds, and therefore their extent.
WAWA (1992) Minimum water level not exceed 11.8 m AHD more than once every 10 years.	Preserves seasonal drying in 9 out of 10 years.	Seasonal drying is linked to increased productivity of aquatic invertebrates, which should result in large numbers of waterbirds (Crome, 1988). The preservation of the natural variability of the water regime may be important in the maintenance of fringing vegetation (Brock and Casanova, 1997). Preservation of the natural seasonality is likely to be critical for the health of the fringing trees, which include *Eucalyptus rudis* and *Melaleuca preissiana* (Froend *et al.,* 1993). Seasonal drying allows for the exposure of mudflats in summer/autumn, which is required by the Long-Toed Stint (a migratory wader) (Directory of Important Wetlands web site). Seasonal drying should reduce the potential for *Gambusia holbrooki* to colonise and achieve high densities, and result in an aquatic invertebrate community typical of seasonal wetlands.

*With an annual difference between maximum and minimum water levels of 1.5 m (from hydrograph in Townley *et al*., 1993 Figure 4.1.7 p89), the maximum water level attained annually should not fall below 1.0m.

** With an annual difference between maximum and minimum water levels of approximately 1.5 m, the maximum water level attained annually should not fall below 0.5 to 1.0m more than once every 10 years.

‘

Steps 10 and 11. Implementation and Monitoring

Biological monitoring regimes should be designed to test performance indicators related to the area of sedge habitat and waterbird and frog breeding success. Biological monitoring should also incorporate an invertebrate monitoring program. Hydrological monitoring should include daily depth measurements to indicate rates of change of depth as well as actual depths.

Conclusion

A lack of historical hydrological data for Thomsons Lake means that the management of the water regime cannot be based on an attempt to reinstate the regime which existed prior to development. WAWA's (1992) management objective, based on the maintenance of ecological character and the protection of waterbird habitat, reflects the ecological values and Ramsar status of the site. The methodology allowed a suitable water regime to be determined based on the requirements of the desired and/or existing wetland flora or fauna.

WAWA's (1992) criteria appear to meet the water regime requirements of the sedge habitat whilst also maintaining suitable water levels and a seasonal/ semi-permanent water regime to meet the requirements of waders. They do not address the threat of increased short-term water level fluctuations. Additional criteria addressing this issue should be incorporated into the current criteria. A monitoring program should ideally incorporate daily water level monitoring and a biotic monitoring program focussed on performance indicators. These should be based on the identified changes to flora and fauna communities identified in the conceptual model.

This report and all references can be downloaded from:
http://www.deh.gov.au/water/rivers/nrhp/wetlands/chapter4-thomsons.html

APPENDIX F. SELECTED S.A. PLANTS AS INDICATORS OF WETLAND CONDITIONS

Grass, rush and sedge species which are indicative of wetland conditions, and occurring in the upland areas of the eastern Seaboard and in the Highveld (from Kotze & Marneweck 1999). These are categorised on the basis of their water requirements (fw=facultative wet; ow=obligate wet), according to the classification presented in Table 8.1 (Text).

Agrostis eriantha	fw		CYPERACEAE (SEDGES)		
Agrostis lachnantha		ow	*Ascolepis capensis*		ow
Andropogon appendiculatus		fw	*Bulbostylis schoenoides*	ow	
Andropogon eucomis		fw	*Carex acutiformis*	ow	
Arundinella nepelensis		fw	*Carex austro-africana*		ow
Brachiaria eruciformis		fw	*Carex cognata*		ow
Diplachne fusca		ow	*Carex glomerabilis*		ow
Echinochloa crus-galli		fw	*Cyperus articulatus*		fw
Echinochloa jubata		fw	*Cyperus denudatus*		ow
Eragrostis lappula		fw	*Cyperus difformis*	ow	
Eragrostis plana	fw(dry climate); f (wet climate)		*Cyperus dives*		ow
Eragrostis planiculmis		ow	*Cyperus fastigiatus*		ow
Festuca caprina		fw	*Cyperus latifolius*	ow	
Fingerhuthia sesleriiformis	ow		*Cyperus longus*	fw?	
Helictotrichon turgidulum	fw		*Cyperus marginatus*		fw
Hemarthria altissima		fw	*Cyperus pulcher*	ow	
Imperata cylindrica	w(dry climate); f(wet climate)		*Cyperus sexangularis*		fw
Ischaemum fasciculatum	ow		*Cyperus sphaerospermus*	ow	
Koeleria capensis	fw		*Eleocharis acutangular*		ow
Leersia hexandra	ow		*Eleocharis dregeana*		ow
Merxmuellera macowanii	fw		*Eleocharis limosa*	ow	
Miscanthus capensis		fw	*imbristylis complanata*		fw
Miscanthus junceus		ow	*Fuirena pubescens*		ow
Panicum coloratum		fw	*Isolepis costata*	ow	
Panicum hymeniochilum	ow		*Isolepis fluitans*		ow
Panicum repens	ow		*Isolepis prolifera*	ow	
Panicum schinzii	fw		*Kyllinga erecta*		fw
Paspalum dilatatum		fw	*Kyllinga melanosperma*		ow
Paspalum distichum		ow	*Kyllinga pauciflora*		ow
Paspalum scrobiculatum	fw		*Mariscus congestus*		fw
Paspalum urvillei	fw		*Mariscus solidus*	ow	
Pennisetum macrourum	ow		*Pycreus cooperi*	ow	
Pennisetum natelense		ow	*Pycreus macranthus*		ow
Pennisetum sphacelatum	ow		*Pycreus mundii*		ow
Pennisetum thunbergii		ow	*Pycreus nitidus*		ow
Pennisetum unisetum		fw	*Pycreus sp1*		ow
Phalaris arundinacea		ow	*Pycreus unioloides*		ow
Phragmites australis		ow	*Rynchospora brownii*		ow
Phragmites mauritianus		fw	*Schoenoplectus brachyceras*		ow
Setaria sphacelata		fw	*Schoenoplectus decipiens*	ow	
Stiburus alopecuroides		fw	*Schoenoplectus paludicola*	ow	
JUNCACEAE (RUSHES)			*Scirpus burkei*		fw
Juncus dregeanus		w	*Scirpus ficinioides*		fw
Juncus effusus		w	*Scleria dietelenii*	ow	
Juncus exsertus/oxycarpus		w	*Scleria dregeana*	ow	
Juncus krausii		w	*Scleria welwitschii*		ow
Juncus lomatophyllus		w	*Scleria woodii*		ow
Juncus punctorius		w	TYPHACEAE (BULRUSHES)		
Juncus tenuis		w	*Typha capensis*	w	

APPENDIX G: DEVELOPING AN INDEX OF BIOLOGICAL INTEGRITY

This is considered a simplistic, but nonetheless, useful introduction to the process of developing an IBI for different variables to be used in assessment of wetland condition.

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Office of Water
Office of Wetlands, Oceans and Watersheds (4502-F)
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Wetland Bioassessment Fact Sheet 5

One method to assess biological integrity of wetlands is to develop an index of biological integrity (IBI) for an assemblage of wetland plants or animals. An IBI is made by combining several biological indicators, called metrics, into a summary index. A well-constructed IBI that can allow scientists to: (1) measure condition, (2) diagnose the type of stressors damaging a wetland's biota, (3) define management approaches to protect and restore biological condition, and (4) evaluate performance of protection and restoration activities.

FOUR STEPS TO CREATE AN IBI

1 Select an Assemblage	2 Test and Evaluate Metrics	3 Combine Metrics into an IBI	4 Test and Validate IBI

1 Select an Assemblage

An assemblage is a group of plant and animals that are combined to form a larger group. Common wetland assemblages include:

- VASCULAR PLANTS
- AMPHIBIANS
- BIRDS
- ALGAE
- MACROINVERTEBRATES (snails, insects, clams, crayfish, etc.)

2 Test and Evaluate Metrics

A metric is a measurable component of a biological system with an empirical change in value along a gradient of human disturbance Scientists can measure many biological attributes of wetlands such as the diversity of amphibians or the number of pollution-tolerant insects. Some of these attributes will provide valuable information about biological integrity and other attributes will not. The goal is to identify **metrics**, which are attributes that show an empirical and predictable change in value along a gradient of human disturbance. The gradient of human disturbance can represent the amount of logging, agriculture, development, impervious surfaces, or other land use or activity in a watershed, or some combination of land use, depending on the purpose of the bioassessment. An example of a metric is taxa richness of macroinvertebrates (the number of taxa of insects, snails, clams, crayfish, etc.). Several states have found that macroinvertebrate richness decreases as a wetland is degraded by human activities.

(**Figure 1**). For illustrative purposes, Figures 1-5 were developed using hypothetical data, but are based on figures that were provided by Dr. James Karr (University of Washington). As Figure 1 shows, there is a clear response to increasing human disturbance and this attribute could be used as a metric.

In contrast, total abundance of macroinvertebrates is often more dependent on natural environmental variability of wetlands and does not show a reliable change in response to human disturbance (**Figure 2**). As Figure 2 shows, there is no clear response to increasing human disturbance and this attribute would not be useful as a metric. In these two examples, total taxa richness of macroinvertebrates could serve as a metric and total abundance could not.

3 Combine Metrics into an IBI

Typically, an IBI is formed by combining at least 7 metrics from one biological assemblage. One approach of combining metrics into an IBI is to assign scores of 1, 3, or 5 to the metrics according to how they respond to human disturbances. For example, the diversity and richness of macroinvertebrate taxa may consistently decrease with increasing human disturbance (**Figure 3**). In this case, we could assign a score 1 to indicate poor conditions, 3 to indicate moderate conditions, and 5 to indicate minimally impacted conditions (**Figure 3**). Another metric, the relative abundance of tolerant taxa [(number of tolerant individuals in sample) / (total number of individuals in sample) x 100], may increase with increasing human disturbance (**Figure 4**). In this case, a wetland dominated by tolerant taxa would receive a low score and a wetland with a small percentage of tolerant taxa would receive a high score .

If 10 metrics were scored in this manner, then the scores could be added together to form the index of biological integrity (IBI) with potential scores ranging from 10 (maximally impacted) to 50 (minimally impacted). The IBI scores should form a relatively straight line when plotted against the gradient of human disturbance (**Figure 5**). Sometimes there will be scores that are far from the line which should be investigated. More often than not, an outlier is either the result of (1) misclassifying the wetland or (2) a stressor, such as acid mine drainage, that is damaging the wetland biota and was not captured by the gradient of human disturbance.

4 Test and Validate IBI

After developing the IBI, the scientists would then test the IBI to see if it accurately detects the effects of human disturbances on the biological assemblage. One approach is to (1) randomly split the data into two halves, (2) develop the IBI on one half of the data, and (3) test the IBI on the other half of the data. The results should be similar. Scientists can also test the IBI on more than one gradient of human disturbance. For example, the scientists may first

A metric is a measurable component of a biological system with an empirical change in value along a gradient of human disturbance

Figure 1: Macroinvertebrate Taxa Richness of 40 Wetlands

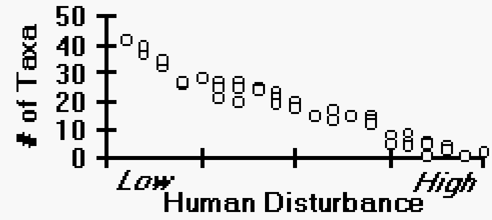


Figure 2: Total Macroinvertebrate Abundance of 40 Wetlands

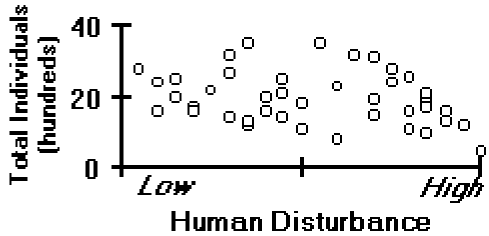


Figure 3: Macroinvertebrate Taxa Richness of 40 Wetlands

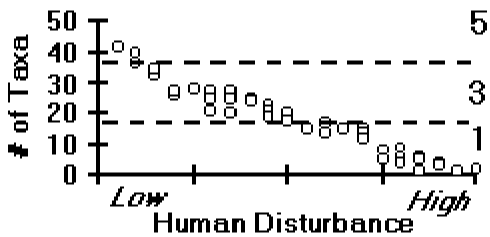


Figure 4: Percent Macroinvertebrate Tolerant Taxa of 40 Wetlands

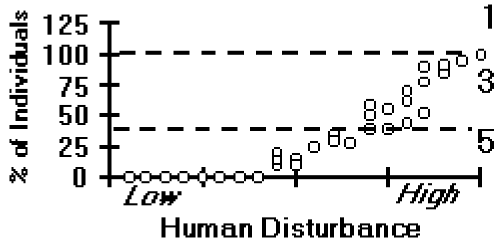
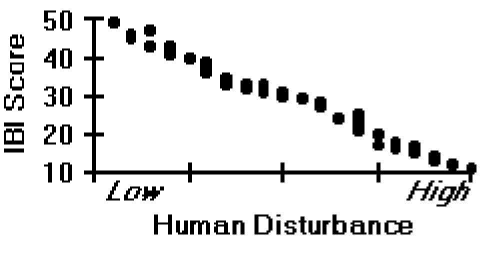


Figure 5: Index of Biological Integrity Scores of 40 Wetlands



develop the IBI with a gradient such as the percent of a watershed that is logged. During subsequent years, they could test the same IBI across another gradient of human disturbance, such as percent of watershed with impervious surfaces or distance of wetlands to nearest road or farm field. Some metrics will consistently show clear patterns regardless of the type of human disturbance used on the X axis.

After testing and validating the index, they could directly measure the health of similar wetlands without having to measure every attribute. They would only have to measure the ten metrics and some basic chemical and physical characteristics of the wetlands to help diagnose the type of stressor(s) damaging wetlands and to develop plans to reduce the impacts. When reporting results of a bioassessment, the IBI score should always be accompanied by a narrative description of the overall site condition, scores of the individual metrics, and a narrative descriptions of each metric as compared to conditions found in reference wetlands of the same type and region.

GLOSSARY OF TERMS

- **Assemblage:** An association of interacting populations of organisms in a given waterbody. Examples of assemblages used for biological assessments include : algae, amphibians, birds, fish, herps (reptiles and amphibians), macroinvertebrates (insects, crayfish, clams, snails, etc.), and vascular plants.
- **Attribute:** A measurable component of a biological system. (Karr, J.R., and E.W. Chu. 1997. *Biological Monitoring and Assessment: Using Multimetric Indexes Effectively.* EPA 235-R97-001. University of Washington, Seattle)
- **Biological Assessment (bioassessment):** Using biomonitoring data of samples of living organisms to evaluate the condition or health of a place (e.g., a stream, wetland, or woodlot).
- **Biological Criteria (biocriteria):** Numerical values or narrative expressions that describe the condition of aquatic, biological assemblages of reference sites of a given aquatic life use designation.
- **Biological Integrity:** "...the ability of an aquatic ecosystem to support and maintain a balanced, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats within a region." (Karr, J. R. and D. R. Dudley. 1981. *Ecological perspective on water quality goals.* Environmental Management 5:55-68)
- **Biological Monitoring (biomonitoring):** Sampling the biota of a place (e.g., a stream, a woodlot, or a wetland)
- **Biota:** The plants and animals living in a habitat.
- **Composition (structure):** The composition of the taxonomic grouping such as fish, algae, or macroinvertebrates relating primarily to the kinds and number of organisms in the group.
- **Community:** All the groups of organisms living together in the same area, usually interacting or depending on each other for existence.
- **Criteria (singular = criterion):** Statements of the conditions presumed to support or protect the designated use or uses of a waterbody. Criteria may be narrative or numeric.
- **Diatom:** Microscopic algae with cell walls made of silicon and of two separating halves.
- **Diversity:** A combination of the number of taxa (see taxa richness) and the relative abundance of those taxa. A variety of diversity indexes have been developed to calculate diversity.
- **Ecological Assessment:** A detailed and comprehensive evaluation of the status of a water resource system designed to detect degradation and if possible, to identify causes of that degradation.
- **Ecological Integrity:** The condition of an unimpaired ecosystem as measured by combined chemical, physical (including physical habitat), and biological attributes.
- **Ecoregion:** Regions defined by similarity of climate, landform, soil, potential natural vegetation, hydrology, and other ecologically relevant variables.
- **Functions:** The roles that wetlands serve, which are of value to society or environment.
- **Habitat:** The sum of the physical, chemical, and biological environment occupied by individuals of a particular species, population, or community.
- **Hydrogeomorphic (HGM) Classification:** A wetland classification system based on the position of a wetland in the landscape (geomorphic setting), dominant sources of water, and the flow and fluctuation of water once in the wetland. Hydrogeomorphic classes include riverine, depressional, slope, mineral soil flats, organic soil flats, estuarine fringe, and lacustrine fringe.
- **Hydrogeomorphic (HGM) Approach:** A functional assessment method which compares a wetland's condition to similar wetland types (as defined by HGM classification) that are relatively unaltered. HGM functions normally fall into one of three major categories: (1) hydrologic (e.g., storage of surface water), (2) biogeochemical (e.g., removal of elements and compounds), and (3) habitat (e.g., maintenance of plant and animal communities).
- **Hydrology:** The science of dealing with the properties, distribution, and circulation of water both on the surface and under the earth.

- **Impact:** A change in the chemical, physical (including habitat), or biological quality or condition of a waterbody caused by external forces.
- **Impairment:** A detrimental effect on the biological integrity of a waterbody caused by an impact that prevents attainment of the designated use.
- **Index (plural = indices or indexes):** An integrative expression of site condition across multiple metrics. An index of biological integrity is often composed of at least 7 metric. (Karr, J.R., and E.W. Chu. 1997. *Biological Monitoring and Assessment: Using Multimetric Indexes Effectively.* EPA 235-R97-001. University of Washington, Seattle)
- **Index of Biological Integrity:** An integrative expression of the biological condition that is composed of multiple metrics. Similar to the Dow Jones Industrial index used for expressing the condition of the economy.
- **Macroinvertebrates:** Animals without backbones that can be seen with the naked eye (caught with a 1 mm^2 mesh net). Includes insects, crayfish, snails, mussels, clams, fairy shrimp, etc.
- **Metric:** An attribute with empirical change in value along a gradient of human influence. (Karr, J.R., and E.W. Chu. 1997. *Biological Monitoring and Assessment: Using Multimetric Indexes Effectively.* EPA 235-R97-001. University of Washington, Seattle)
- **Pollution:** The Clean Water Act (§502.19) defines pollution as "the [hu]man-made or [hu]man-induced alteration of chemical, physical, biological, and radiological integrity of water."
- **Reference Condition:** Set of selected measurements or conditions of minimally impaired waterbodies characteristic of a waterbody type in a region.
- **Reference Site:** A minimally impaired site that is representative of the expected ecological conditions and integrity of other sites of the same type and region.
- **Taxa (singular = taxon):** A grouping of organisms given a formal taxonomic name such as species, genus, family, etc.
- **Taxa Richness:** The number of distinct species or taxa that are found in an assemblage, community, or sample.
- **Water Quality Standard:** A legally established state regulation consisting of three parts: (1) designated uses, (2) criteria, and (3) antidegradation policy (See Fact Sheet 7).
- **Wetland:** Those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, an similar areas. (Cowardin *et al.* 1979. *Classification of Wetlands and Deepwater Habitats of the United States.* U.S. Department of the Interior. Fish and Wildlife Service. FWS/OBS-79/31)