WETLANDS CONSERVATION REPORT SERIES

Number 4

Manual of Wetlands Management

DEPARTMENT OF NATURAL RESOURCES AND ENVIRONMENT - VICTORIA

Wetlands Conservation Report Series
Number 4

MANUAL
of
WETLANDS MANAGEMENT

July 1996

National Parks Service
Department of Natural Resources and Environment
1/250 Victoria Parade
East Melbourne, Victoria 3002

Assisted by the Australian Nature Conservation Agency

CONTENTS

ABOUT THIS MANUAL

ACKNOWLEDGMENTS

This manual was compiled and edited by Grant Hull and Elizabeth Beovich with input from Janet Holmes and other staff of the National Parks Service NRE.

Thanks are extended to all the people who made comments on the document throughout the compilation process.

The funding support provided by the Australian Nature Conservation Agency (ANCA) to finalise this manual is acknowledged with thanks.

LIST OF CONTRIBUTORS

Chapter 1: Introduction
Grant Hull and Elizabeth Beovich (NRE)

Chapter 2: Techniques for Survey, Inventory and Classification
Margaret Beilharz (Deakin University) and Ecoscape Consulting Services

Chapter 3: Landscape Assessment
Paul Dartnell (NRE)

Chapter 4: Water Management
Christopher Gippel (Department of Civil and Environmental Engineering, University of Melbourne)

Chapter 5: Livestock Grazing
Grant Hull (NRE) and Ecoscape Consulting Services

Chapter 6: Fire Management
Grant Hull (NRE) and Ecoscape Consulting Services

Chapter 7: Techniques Applicable to the Restoration and **Revegetation** of South-eastern Australian Freshwater Wetlands Restoration
Grant Hull (NRE) and Ecoscape Consulting Services

Chapter 8: Aquaculture
Doug Hume Consulting Services and Western Ecological Consultants

1 Introduction

Australia's wetlands are important resources for their environmental, recreational, aesthetic and commercial values. Appropriate management is essential if wetlands are to be maintained, enhanced and conserved. This manual of wetland management provides background information to facilitate such appropriate management.

Wetlands in Australia and worldwide are threatened by many processes. These include fire, grazing, altered hydrology, changes to landscape and commercial activities. In order to conserve wetlands and continue to meet the international agreements of the Ramsar Convention and JAMBA and CAMBA, wetlands management must address these and other threatening processes. It also needs to address potentially threatening activities such as aquaculture to ensure that they are ecologically sustainable.

1.1 WETLAND DEFINITION

1.1.1 International

The definition of wetlands under the Convention on Wetlands of International Importance (the Ramsar Convention) is:

> Wetlands are:
> areas of marsh, fen, peatland or water, either natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including area of marine water the depth of which at low tide does not exceed six metres.

1.1.2 National

No Australia-wide definition of wetlands exists, although at a technical workshop convened jointly by the Australian National Parks and Wildlife Service and the Bureau of Rural Resources in August 1991 most participants agreed that the Ramsar Convention definition of wetlands should be used for wetland inventory in Australia (ANPWS and Bureau of Rural Resources undated).

In practice, most wetland survey and inventory work in Australia restricts itself to a subset of those wetlands covered by the Ramsar definition (Pressey and Adam in press).

1.1.3 Victorian

A number of related, but varying, wetland definitions are used in Victoria. Corrick defines wetlands in accordance with the Ramsar Convention definition (above) but excludes beaches, wet heaths, stream courses and tidal areas below low tide

(Corrick[1], pers. comm.). This definition is the basis of the Victorian wetland inventory and thus is adopted for this report. Irrigated agricultural land is not included.

Wetlands are defined in the Wetlands Conservation Program for Victoria 1988 (CFL et *al.* 1988: 3) to be:

> areas of marsh, fen, peatland or water, whether natural or artificial, permanent, seasonal or cyclical, with water that is static or flowing, fresh, brackish or salt, including mudflats and mangrove areas exposed at low tide.

The currently accepted definition of wetlands in Victoria has been adapted from the classification given by the International Union for the Conservation of Nature and Natural Resources (IUCN) which is:

> Wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent, seasonal or cyclical, with water that is static or flowing, fresh, brackish or salt, including mudflats and mangrove areas exposed at low tide

It includes:

- swamps, billabongs and other depressions on floodplains adjacent to streams;
- all impoundments larger than one hectare either wholly or, in the case where lands are permanently flooded to a depth of more than six metres, the margins.

It excludes:

- marine beaches;
- lands permanently flooded to a depth of more than six metres;
- stream sections of rivers and creeks;
- artificial water supply and drainage channels and associated borrow pits;
- impoundments less than one hectare;
- freehold land used for agriculture and covered by irrigation water.

Publicly owned wetlands include wetlands occurring on any Crown land or on land vested in any public authority. Wetlands on land held by Municipalities under freehold title are not regarded as publicly owned.

1.2 THE NEED FOR WETLAND CONSERVATION

Wetland ecosystems have suffered through many human activities, including:

- drainage;
- land filling;
- flooding and modified hydrological regimes for water supply and irrigation;

---

[1] A. Corrick, Arthur Rylah Institute, Heidelberg.

- clearing for timber and agriculture leading to erosion and increased sedimentation;
- salinisation as a result of irrigation, clearing and saltwater disposal;
- pollution from contaminated runoff and direct effluent disposal;
- grazing of stock;
- mining for sand, gravel, clay, shells and other materials;
- introduction of exotic plants and animals;
- acidification due to acid rain;
- overfishing;
- lead poisoning of wildfowl from lead shot; and
- recreational activities.

Wetlands are an integral part of the natural environment and provide humans with products, services and less tangible benefits (Table 1a). Intangible benefits gained by humans arise from the valuing of wetlands for their intrinsic (or non-use) values, including the belief held by some people that wetlands and their many component species and communities have a right to exist and flourish (Stone 1991).

Table 1a Benefits provided by wetlands (Dugan 1988, CFL *et al.* 1988).

Products:	• water • fish • birds and other wildlife • timber • forage resources • energy (eg from peat or water) • fibre
Ecosystem functions:	• flood mitigation • erosion control • groundwater recharge and discharge • water purification • biomass export • habitat for plant and animal species for propagation, dispersal and feeding • maintenance of biodiversity and ecological processes

Social services:	• recreation • tourism • education • scientific research • cultural uses • historical heritage • archaeological heritage • landscape values
Intangible benefits:	• Intrinsic values

Wetland loss can impose an economic cost on the community to replace the benefits provided by wetlands. Conservation measures are therefore a wise and proactive step to ensure that wetland values and benefits are maintained. Wetland creation is generally more expensive than protection.

In some parts of the world, for instance California USA, over 90% of natural wetlands have been lost or highly degraded (Dugan 1988). In Victoria, there has been a decrease in wetland number by 22%, and a decrease in wetland area by one-third, since European settlement (Corrick pers. comm.). Hence, there is recognition that steps must be taken to conserve our wetland estate.

1:3 WETLANDS CONSERVATION POLICIES

1.3.1 International agreements

Australia is signatory to three international agreements relating specifically to the conservation of wetlands and wetland dependent fauna; the Ramsar Convention, the Japan-Australia Migratory Birds Agreement (JAMBA) and the China-Australia Migratory Birds Agreement (CAMBA).

- *Convention on Wetlands of International Importance (Ramsar Convention)*

  Under the Ramsar Convention, contracting parties are required to, amongst other things: designate wetlands within their territory which are of international significance; promote the conservation of the listed wetlands and other wetlands and waterfowl; and encourage research, exchange of information and training of wetland managers. Ten wetland areas were nominated by the Victorian Government in 1982 and have been declared wetlands of international importance under the Ramsar Convention.
- *Japan—Australia Migratory Birds Agreement (JAMBA) and China—Australia Migratory Birds Agreement (CAMBA)*

JAMBA and CAMBA are bilateral agreements between the governments of the respective countries and the Australian government, in which both parties pledge to protect the habitats of listed birds which migrate between the two countries. Many of the listed species are waterbirds which use Victoria's wetlands. Individual wetland sites are not listed under JAMBA and CAMBA.

1.3.2 National policies

The Register of the National Estate

The *Australian Heritage Commission Act* 1975, provides for the establishment of the Australian Heritage Commission which, amongst other tasks, compiles an inventory of places of national significance entitled the Register of the National Estate. The National Estate is defined as:

> those places being components of the natural environment of Australia, or the cultural environment of Australia, that have aesthetic, historic, scientific or social significance or other special value for future generations, as well as the present community.

The Act requires Commonwealth Ministers and their agencies to consider any effects on the National Estate areas of proposals for which they have a decision-making role, and to not take any action that adversely affects a listed site unless there is no feasible and prudent alternative (Australian Heritage Commission 1993).

Many wetland areas are included in sites listed on the Register of the National Estate, either specifically for their wetland values, or as sites within areas nominated for other values. A complete listing of Victorian wetlands included on the Register of the National Estate is provided in Deluca and Williams (1992). The Register of the National Estate does not at present cover all wetlands of national significance in Victoria; for instance, not all the Ramsar listed wetlands are included.

1.3.3 Victoria

State wetlands initiatives

The Victorian Government has introduced a number of significant initiatives that support wetlands management and conservation. These include:

- management of more than 300 wetland-dedicated conservation reserves by the Victorian National Parks Service.
- the Victorian Catchment and Land Protection Council with supporting legislation in the form of the *Catchment and Land Protection Act* (1994).
- the Coastal and Bay Management Council (CBMAC) which will oversee and co-ordinate planning from the land to the three mile nautical limit.
- the Land Conservation Council Marine and Coastal Special Investigation which has made recommendations to government on the protection of significant environmental values and the sustainable use of these areas.
- support and advice to private landowners through schemes including the Land for Wildlife scheme.

- completion of mapping and classification of all of Victoria's 18 000 wetlands (over one hectare in extent).

The Government has endorsed the National Strategy for Ecologically Sustainable Development and the draft National Strategy for the Conservation of Australia's Biodiversity. The Victorian biodiversity strategy is expected to be released in 1996. The Victorian Wildlife Atlas has been expanded to include freshwater invertebrates.

Wetlands Conservation Program for Victoria (1988-92)

This background document is a valuable guide to the management of Victorian wetlands. The overall objective of the Program (CFL *et al.* 1988: 3): was 'to ensure that wetlands on public and private land are managed so that they collectively provide the complete range of conservation, social and economic values for the community'.

Specific ecological conservation goals included that 'wetlands in Victoria are protected and the complete range of wetland types present at the time of European settlement is maintained' and 'there is adequate representation of wetland types in a state-wide network of publicly owned conservation reserves' (CFL *et al.* 1988: 3).

A fundamental part of the Program was the identification of 'high value' wetlands, to which resources were to be directed. The Program established a Wetlands Scientific Committee whose primary role was to assess the ecological values of Victorian wetlands. A wetland was considered high value if it met one or more of the criteria adopted by the Wetlands Scientific Committee (Newton in prep.). These criteria are an amendment of the interim criteria contained within the Wetlands Conservation Program (CFL *et al.* 1988).

Flora and Fauna Guarantee

The *Flora and Fauna Guarantee Act 1988* provides a legislative and administrative framework for the conservation of biodiversity in Victoria. The Act provides for listing of threatened taxa, communities and potentially threatening processes; action statements for future management, interim conservation orders to protect critical habitats, protected flora controls and community education and cooperation. Thus, protection for threatened wetland taxa and communities can be provided under the Act.

The *Flora and Fauna Guarantee Strategy: Conservation of Victoria's Biodiversity* outlines how the flora and fauna conservation and management objectives of the Act are to be achieved and confirms the objectives of the Wetlands Conservation Program to protect the values of all high value wetlands (DCE 1992).

Western Wetlands Program

An 'Agreement to a co-operative program for the Western Wetlands' was signed in 1986 between the then Department of Conservation, Forests and Lands (now Natural Resources and Environment) and the Melbourne and Metropolitan Board of Works (now Melbourne Water Corporation). The two parties agreed in principle to participate in:

a Western Wetlands Program, for wetlands in the vicinity of Port Phillip Bay between the Maribyrnong River and Hovells Creek, which will promote the following principles:

1 Conservation of the Western Wetlands; their flora, fauna, cultural and landscape values.
2 Education of the public to a greater appreciation of the Western Wetlands and a commitment to their preservation.
3 Development of appropriate facilities for education, recreation, and tourism for all sections of the public.
4 Encouragement of the collection of scientific information on the Western Wetlands and their value.

2 Techniques for survey, inventory and classification

2.1 INTRODUCTION

Wise management of wetlands must be based on a thorough knowledge of the wetland estate and a systematic application of that information to decision-making. The six major steps in a strategy which will ensure that conservation and management efforts are directed towards high priority wetlands are outlined below.

1	Survey	Identify, map and describe wetlands. Attribute information for a state-wide inventory must be collected in a standard way, be of high quality, be flexible in application and be relatively quick and easy to collect to enable state-wide coverage.
2	Inventory	The inventory provides baseline data on the status of the resource for decision-making, including the information required for classification.
3	Classification	An ecological classification provides a basis for biological conservation and management and will enable broad comparisons to be made between wetland types (ANPWS and Bureau of Rural Resources, undated). The classification must be based on ecological wetland characteristics and the resulting wetland types must be relatively homogeneous and distinguishable from other wetland types (Pressey and Bedward 1991).
4	Evaluation	Assess the conservation values of wetlands to determine priority for management. Two major concepts underlie ecological evaluation: i Some sites are considered of great ecological significance because of some outstanding feature (Peterken 1968; Larson 1976; Pressey 1984). These include sites of unusual diversity or productivity; those in pristine condition; those supporting rare or endangered species and sites important for particular reasons, such as feeding grounds for migratory animals, breeding grounds or nursery areas. Such sites have traditionally been regarded as sites of high conservation value.

	ii The second concept, which has received greater prominence in recent years with the emphasis on biodiversity, is that a reserve system should encompass the range of biological or genetic variation in a given region (Peterken 1968; Austin and Margules 1986; Nilsson 1986). Achieving a representative reserve system will not only ensure the conservation of rare and endangered species and ecosystems but will also ensure the protection of species that are now common and ecosystem types that otherwise lack attributes considered significant.
5 Management	Implement management actions for high priority wetlands.
6 Monitoring	Monitor both the implementation of the management actions and the condition of the wetland estate. Feedback from this stage should lead to modifications of approach where necessary.

This report outlines the Victorian approach to the first three stages of wetland management; namely, survey, inventory and classification.

Wetland survey, inventory and classification in Victoria were developed under the Wetlands Conservation Program for Victoria (CFL *et al.* 1988), building on a solid base of wetland surveying, mapping and inventory undertaken by Andrew Corrick and colleagues at the Arthur Rylah Institute for Environmental Research (ARI), Department of Natural Resources and Environment (NRE) (Corrick and Cowling 1975, 1978; Corrick and Norman 1980; Corrick 1981, 1982; Norman and Corrick 1988).

The recent developments, including an ecological classification of wetlands based on a 'minimum data set', a readily accessible wetland inventory (the NRE Regional Wetland Database), and a standard method of field survey to obtain the minimum data set and additional inventory data, are described in this report. These methods were designed to support the Program's wetland evaluation procedure (Newton in prep.), specifically in regard to ecological conservation value assessment. The *Regional Wetland Database User Manual* (Beilharz *et al.* 1993) gives a complete description of the Regional Wetland Database and instructions for its use.

2.2 NATIONAL APPROACH TO WETLAND SURVEY, INVENTORY AND CLASSIFICATION

The only attempt to produce an Australia-wide classification of wetlands is that of Paijmans *et al.* (1985), who developed a hierarchical wetland classification system of landform categories, water permanence classes and geomorphic origin subclasses (Appendix 2a). It was intended as a broad scheme, which could be used to classify and map wetlands across Australia.

A 1:2 500 000 map summarising the classification information was produced (Paijmans *et al.* 1985). This system has not been taken up Australia-wide, but is being used in the Northern Territory.

McComb and Lake (1988), following a workshop on wetland conservation in Adelaide in 1986, suggested the data set given in Table 2a as a standard for wetland surveys. The absolutely essential information included only the area, location and conservation status of the wetland. The workshop did not, however, result in any consistency of approach across Australia.

Table 2a Data set of McComb and Lake (1988)

I. Absolutely essential
    a area
    b location (lat./long.)
    c present conservation status
II. Of high importance
    d geomorphological location
    e geology/substrate
    f vegetation structure
    g context (ie relationship to other wetlands in the area)
    h regional land use
III. Significant in any full evaluation
    i water flow
    j permanence
    k morphometric features (in addition to area)
    l thermal regime
    m water chemistry
    n maximum species list
    o threats to existence

A workshop in Newcastle in February 1991, resulted in recommendations on a consistent approach to wetland inventory. The workshop recommended that:

1 a broad definition of wetlands be developed for use in wetland inventory and conservation programs by all agencies and organisations;

2 a classification of wetland types be developed and accepted for use at an Australia-wide level; and

3 a core data set, with strict protocols for data collection and formats of data sets, be established and advocated as a minimum requirement for all Australian inventories of wetlands (Donohue and Phillips 1991).

A draft discussion paper (Barson and Williams 1991) was circulated prior to a follow-up workshop in Canberra in August 1991. Workshop participants from all states and territories agreed that a minimum data set for wetland inventory should be established, and that it should be based on attributes which could be collected on a single visit to a site by a non-specialist. A final set of data was agreed on (Table 2b) although details of how the attributes were to be measured were not.

Table 2b Australian Minimum Data Set (from ANPWS and Bureau of Rural Resources, undated)

Record identifier

- Accurate location
- Name of wetland—if known
- Compiler's name and contact details
- Date and time

Essential information

Landform
Water regime—supply, frequency of inundation
Water chemistry (pH, salinity, conductivity, colour, turbidity)
Dominant plant growth form
Area

Desirable information

Land-use—local and in the catchment
Impacts or threatening processes
Species (presence/absence)
Groundwater (depth, salinity)

Derived from other sources

Wetland type
Land tenure
Conservation/management status
Climatic regime
Elevation
Rare, threatened or endangered species present
Biophysical or biogeographic region

Although a number of participants expressed an interest in field comparisons of some of the classifications in use in Australia, no consistent approach to wetland classification arose from the workshop. (Similarly, there is no consistency in state and territory approaches to wetland evaluation).

The Directory of Important Wetlands in Australia (Australian Nature Conservation Agency 1993) brings together significant information on wetlands from all states and territories. In line with similar directories produced for Asia and Oceania in conjunction with the International Waterfowl and Wetland Research Bureau (IWRB), the Australian directory uses the Ramsar wetland classification (slightly modified for Australian wetlands) as its basis. Apart from Tasmania and South Australia, however, state and territory agencies do not use that classification system in their inventories (Pressey and Adam in press).

There is also no consistency in state and territory approaches to wetland evaluation, except in the case of the Directory of Important Wetlands in Australia, for which criteria based on the Ramsar and Victorian criteria were adopted.

2.3 WETLAND SURVEY, INVENTORY AND CLASSIFICATION IN VICTORIA

An inventory of Victoria's wetlands was initiated by Corrick and colleagues at the ARI, NRE Heidelberg, in the 1970s and has recently been completed (Corrick and Cowling 1975, 1978; Corrick and Norman 1980; Corrick 1981, 1982; Norman and Corrick 1988). This work provides basic location, mapping and classification information on the estimated 18 000 wetlands over one hectare in size in Victoria. Wetlands are divided into categories based on salinity, depth and duration of inundation (plus categories for sewage ponds and salt evaporation basins), and then into subcategories based on dominant persistent vegetation type, depth, modification (eg impoundments), salinity (eg hypersaline lakes) or tidal regime (eg intertidal flats) (Table 2c).

Corrick wetland survey information and digitised wetland location and boundary information are held in the ARI Wetland Database and have also been transferred to the NRE Geographic Information System (GIS).

The primary concern about using the Corrick classification (which was designed to classify wetlands as habitat for waterbirds) for wetland evaluation was that Corrick wetland categories may include ecologically distinctive wetland types. This results from the categories being very broad; for instance only two salinity categories, fresh and saline, are identified (except for semi-permanent hypersaline lakes, which are a subcategory). The categories reflect the duration for which water will be available to waterbirds, but do not distinguish between different landforms or geomorphic origins. Finally, a wetland may be classed as the same category as another wetland yet support quite different species and communities as a result of a widespread geographical/ biophysical difference.

Hence a revised classification system was developed, one which would identify ecologically different wetland types (section 2.4). This ecological classification is the basis for the Victorian minimum data set. A standardised wetland field survey form has been developed to enable the systematic collection of the extra data required (section 2.5), and a new wetland inventory, the Regional Wetlands Database, has been developed to encompass the additional data and make it widely available (Beilharz et *al.* 1993).

Table 2c Wetland categories and subcategories used in ARI surveys (Corrick and Norman 1980, Corrick pers. comm.)

Category (Depth; Duration of Inundation) **Subcategory**	**Category** (Depth; Duration of Inundation) **Subcategory**
1 Flooded river flat (depth <2 m) **2 Freshwater meadow** (depth <0.3 m; inundation <4 mo/yr) 1 Herb-dominated 2 Sedge-dominated 3 Red gum-dominated 4 Lignum-dominated 5 Black box-dominated 6 Cane grass-dominated	**5 Permanent open freshwater** (permanent inundation) 1 Shallow (<2 m) 2 Deep (> 2 m) 3 Impoundment 4 Red gum-dominated 5 Cane grass-dominated 6 Dead timber 7 Black box-dominated 8 Rush-dominated 9 Reed-dominated 10 Sedge-dominated 11 Shrub-dominated 12 Lignum-dominated
3 Shallow freshwater marsh (depth <0.5 m; inundation <6 mo/yr) 1 Herb-dominated 2 Sedge-dominated 3 Cane grass-dominated 4 Lignum-dominated 5 Red gum-dominated 6 Black box-dominated 7 Dead timber 8 Rush-dominated 9 Reed-dominated	**6 Semipermanent saline** (depth <2 m; inundated <4-12 mo/yr) 1 Salt pan 2 Salt meadow 3 Salt flats 4 Sea rush-dominated 5 Hypersaline lakes 6 Melaleuca-dominated 7 Dead timber
4 Deep freshwater marsh (depth <2 m; permanent inundation) 1 Shrub-dominated 2 Reed-dominated 3 Sedge-dominated 4 Rush-dominated 5 Open water 6 Cane grass-dominated 7 Lignum-dominated 8 Red gum-dominated	**7 Permanent saline** (depth: shallow <2; deep >2; permanent inundation) 1 Shallow 2 Deep 3 Intertidal flats

2.3.1 Relationship between the minimum data set, the wetland field survey form and the Regional Wetland Database

The availability of the Regional Wetland Database has removed the need for the wetland field survey form (which is essentially required as a field data sheet) to contain a lot of the reference and inventory information for which it was previously designed. Whereas in drafts of this work (eg Beilharz 1990) the survey form and the minimum data set were considered synonymous, now the minimum data set of essential information can be distinguished from other data which are *useful* but not essential. Also, data which need to be collected in the field can be distinguished from data obtained in the office, as the latter can be entered directly into the Regional Wetland Database (Beilharz *et al.,* 1993). It is possible, however, to obtain printouts of reports from the database containing all fields; these can be used as data sheets where appropriate.

Hence, the Wetland Field Survey form given here (Appendix 2b) is restricted to the field survey component. More detailed field surveys (eg for management purposes) would, of course, collect additional data.

In accord with the national approach, the minimum data set is restricted to the information absolutely essential for all wetland surveys, rather than the more inclusive approach taken earlier, where all sorts of very useful, but not essential, information was included.

2.4 AN ECOLOGICAL CLASSIFICATION OF VICTORIAN WETLANDS

An ecological classification is successful if it results in classes that are at once ecologically homogeneous and ecologically distinct from other classes (Pressey and Bedward 1991). Thus, the classification should be based on attributes which are likely to lead to ecological differences between wetlands. The general consensus from both existing wetland classifications (Appendix 2c) and suggested minimum data sets (Tables 2c and 2d) is that the most important attributes are the wetland geomorphology, hydrology and water chemistry. These factors, along with a biophysical regionalisation which incorporates geological and climatic differences between areas, provide a solid foundation for distinguishing ecological wetland classes. Vegetation, which is often used as an important attribute in classification, is as much a reflection of these factors as an additional attribute to be considered.

Thus, the proposed primary level of classification of wetland types for Victoria is on the basis of:

- biophysical region,
- geomorphology,
- hydrology, and
- water chemistry.

2.4.1 Survey methodology

The following requirements were considered in devising an ecological dassification system for Victoria (some requirements relate to the attributes to be used, others to the methodology).

- Existing classification system (eg in use in other states or territories) should be used, if suitable, in preference to devising a new scheme.
- Existing data and standards should be used where possible.

- The system should be flexible so that:
  —new wetland types can be incorporated;
  —wetlands can be classified as they are surveyed;
  —it is relevant to a variety of uses (particularly uses which require different levels of discrimination);
  —it can be modified in future to comply with a national scheme; and
  —it can be modified, if necessary, following evaluation.

Pressey and Bedward (1991) discuss the advantages and disadvantages of various classification methodologies. A priori systems (where the classes are determined in advance of the field surveys) can lead to problems with inappropriate classes into which wetlands do not fit well. A posteriori systems allow the classes to be discovered after the data are collected, thus the classification system does not pre-empt the result. Numerical classification systems (where the attributes of individual wetlands are grouped on computer on the basis of similarity or dissimilarity) are useful for when many attributes are collected on each wetland. However, including additional sites necessitates redoing the entire process, and individual wetlands may be assigned to different categories. Thus, a numerical grouping procedure is not suitable for situations in which data are going to be collected over a long period of time in a number of different surveys, such as in Victoria.

An hierarchical classification (where attributes are used to distinguish between classes of successively greater discrimination) is advantageous in that it allows the classification to be used to different levels of detail. In a well-designed hierarchical classification system, each attribute is considered at only one level and, conversely, each level of the hierarchy distinguishes groups on the basis of only one attribute. Some allowance must be made between the different application of attributes to different wetland types (eg inland versus marine), but a regular arrangement of attributes ensures that the classification scheme is straightforward and easy to comprehend.

An hierarchical classification methodology, which avoids the disadvantages of the priori fixed classification system and the posteriori numerical grouping, is suggested for Victoria. The approach is:

to define the attributes that will be used in the classification;
to collect the data relevant to those attributes independently of other attributes;
to sort the wetlands into groups on the basis of those attributes, so that a wetland type will contain wetlands which have similar attributes; and
to apply a biophysical regionalisation to the system.

The resulting classification is similar in approach, although different in detail, to some other wetland classification methodologies in use around Australia (eg Paijmans et *al.* 1985, Cowardin et al. 1979).

Flexibility of the classification system for future modification is maintained by collecting primary rather than categorical data from the outset for quantitative attributes. That is, the data should be collected in the form of direct measurements (eg pH = 9.2) rather than the class (eg Alkaline pH > 8). Recording the actual measurement allows revision of the classification system at a later date if necessary (ANPWS and Bureau of Rural Resources undated). The primary data will also be more useful for other purposes, such as management or monitoring, than the broad categories which are used in a classification of this type.

Nevertheless, the classification system uses categories for quantitative attributes such as pH and salinity, for a number of reasons:

1. The classification is a simple one and to recognise slight variations in such attributes would provide more detail than is required.
2. Such attributes vary on a daily, seasonal and annual basis, and it would not be reasonable to assume a greater accuracy from only one or a few measurements.

Categories have been designed to account for the variability of measurements such as salinity by offering a variety of ranges (eg saline to hypersaline or slightly saline to hypersaline) so that the category incorporates the variation found within the wetland over time. To decide into which category the wetland falls will require readings over a number of different seasons.

Descriptive categories, such as for water regime, have also been designed to encompass the variation found between years, thus a wetland is typified as seasonal if it floods and dries in most years; however it may not flood in a very dry year or it may not dry out in a very wet year. Again, observations over more than one visit are required to make such judgements. Local knowledge will be very valuable in assigning wetlands into water regime categories.

Flexibility in the classification is also provided by the independent collection of attributes and subsequent sorting into groups. If a previously unidentified class of, say, landform is identified, it can simply be added into the classification system. Similarly, not all potential classes will be filled; however, they are not excluded from the start in case examples arise which fit into those classes.

2.4.2 Classification schemes in use around Australia

Many different wetland classification systems are in use around Australia (Pressey and Adam in press). A small number of these could be said to have general use in a particular state or territory, in that they are being used by the relevant department of conservation in more or less extensive surveys. In some states, such as NSW, a variety of methods has been used and no one method can be said to dominate.

Classification methods in general use, which could potentially be applicable across Australia, are shown in Table 2d, and discussed further below.The Victorian approach of Corrick and Norman (1980) has already been discussed and the Victorian ecological wetland classification is being outlined in this paper.

A number of studies in Western Australia have used the geomorphic approach to the classification of inland wetlands of Semeniuk (1977). This is currently being expanded to include classes not found in south-west Western Australia so that it can be applied worldwide (Semeniuk and Semeniuk in press). The geomorphic

Table 2d **Wetland survey methods in general use around Australia**

State	Survey method	Source
Western Australia	Geomorphic approach	Semeniuk 1987, Semeniuk and Semeniuk in press
Northern Territory	Australian classification of wetlands	Paijmans *et al.* 1985
Queensland	Classification of the wetlands and deepwater habitats of the United States	Cowardin *et al.* 1979
Victoria	Classification of wetlands (as waterbird habitat) Ecological wetland classification	Corrick and Norman 1980, This paper
Tasmania	Ramsar classification	Ramsar Bureau

approach is based on wetland types defined by landform morphology and water permanence, for which terms have been coined where necessary (Appendix 2d). Modifiers are used to elaborate on the primary wetland types, including; shape, size and the level and consistency of water salinity (Semeniuk 1977). The classification is intentionally designed to emphasise landform (shape and scale) and water characteristics over climatic, geological, geomorphological and vegetational attributes on the basis that the former would identify the underlying similarity of wetlands across a wide range of settings.

The classification of wetlands by Paijmans *et al.* (1985) is being used in the Northern Territory. The classification includes inland and marine wetlands and uses landform, water regime and geomorphic origin attributes. Wetlands are not distinguished on the basis of water chemistry (salinity or pH) which is an important determinant of a wetland's ecology, nor is a biophysical regionalisation used to distinguish between wetlands in different biogeographic areas. However, in a 1:2 500 000 map produced to display the wetland distribution in Australia, saline and non-saline wetlands were distinguished and six broad geographic settings, with subclasses, were identified. Victorian wetlands fell into one of three settings, Murray Lowlands, Southeastern Uplands or Victorian Coast Zone.

Wetlands in Queensland are classified using the hierarchical method of Cowardin *et al.* (1979) of the USA (Appendix 2a). In this approach, wetlands and deepwater habitats are divided into systems which share similar hydrologic, geomorphologic, chemical or biological factors. The five systems are marine, estuarine, riverine, lacustrine (lacking vegetation) and palustrine (vegetated). Subsystems are distinguished largely on the basis of water depth/permanence (eg tidal/subtidal); or limnetic (deep water)/littoral (shoreline to a depth of 2 m)); and for riverine systems, gradient and water velocity are also factors. Classes are distinguished on the basis of substrate (mostly) or vegetation type (dominant life form), and can be further divided into sub-classes on the basis of predominant life form and dominance types, or on the basis of the dominant species (plants or sedentary or sessile animals). Additional information is provided by modifiers at the class and lower levels, eg water regime, salinity, pH, and modifications. Regional variations between a given wetland type are also important. In the USA, ecoregions of the USA were identified. Queensland uses the biophysical provinces of Stanton and Morgan (1977).

Tasmania has previously used a system similar to that of Corrick and Norman (1980) for a state-wide inventory (Blackhall 1986), but is now using the Ramsar wetland classification (Pressey and Adam, in press). The Ramsar classification system is a non-hierarchical list of wetland types (Appendix 2a), and as such does not fulfil one of the requirements of a classification methodology, namely the ability to group wetlands into more or fewer classes as required. It is also not explicitly based on ecological attributes (although the classes are expected to be ecologically distinct), and it is an a *priori* system which could lead to new wetland types being forced into categories into which they do not fit comfortably.

The systems of Semeniuk (1987), Cowardin *et al.* (1979) and Paijmans *et al.* (1985) are similar in having a hierarchical structure based on attributes such as landform, water permanence and, except for Paijmans *et al.* (1985), water chemistry. However, none of these systems was considered entirely appropriate to apply to Victoria without modification. Semeniuk's geomorphic approach is based on the morphology of wetlands rather than their geomorphic origin. It also only applies to inland wetlands. Paijmans *et al.* (1985) approach is lacking water chemistry attributes. The Cowardin *et al.* (1979) system also only gives a superficial geomorphological description, emphasising substratum or vegetation types to differentiate classes.

2.4.3 Classification of wetlands in Victoria

Elements of the above classification schemes were used where suitable, in combination with attributes already available for Victorian wetlands, to develop an ecological classification scheme for Victorian wetlands.

A hierarchical classification framework has been developed which will distinguish between wetland types on the basis of geomorphology, hydrology and physicochemical characteristics within a biophysical framework. The seven classification attributes chosen (I-WI) are given in Table 2e.

Table 2e Attributes for ecological classification of Victorian wetlands

System	I Inland or Marine
Biophysical region	II Geomorphic unit
Geomorphology	III Wetland morphology
	IV Wetland origin
Hydrology	V Water regime
Water chemistry	VI Conductivity
	VII pH

The assumption that these attributes will result in ecologically distinctive and meaningful wetland classes needs to be assessed.

Classification is achieved by sorting individual wetlands into groups on the basis of the above attributes. The highest level of distinction is into the inland or marine system followed by the biophysical region. Thus, within the inland system, wetlands are distinguished on the basis of biophysical regions, within a particular region they are further distinguished on the basis of morphology, and so on. There are potentially thousands of wetland types, however many combinations (such as marine wetlands in the east Victoria uplands) are not possible.

The aim of the ecological classification is to classify wetlands as a whole (ie a wetland is classified as a unit) into a category which encompasses the dynamic variation inherent in many types of wetlands. The attributes are further elaborated below.

System

The primary distinction is between wetlands which are directly influenced by the marine environment (marine) and those which are not (inland). This difference is so fundamental that many systems deal only with non-marine wetlands. Wetlands are considered part of the marine system if they receive some water of marine origin, eg tidal flats and estuaries. For many attributes (eg water regime) the possible categories differ for marine and non-marine wetlands.

Geomorphic units

The Geomorphic Units of Jenkin and Rowan (1988) and Rowan (1990) are used to provide a biophysical overlay to the ecological wetland classification. Nine Geomorphic Units and 29 sub-units (used as 'Geomorphic Units' in the classification) have been described for Victoria. Geomorphic Units are high level groupings of land systems, a complex mapping unit based on climate, lithology, landform, soil and indigenous vegetation (Rowan 1990). It is thus a reasonable assumption that wetlands of otherwise similar attributes occurring in different Geomorphic Units will differ ecologically. This assumption should be tested and verified.

Wetland morphology

The wetland morphology (cross-sectional shape, modified from Semeniuk (1977), Semeniuk and Semeniuk (in press)) provides a basic differentiation of wetland types. Similar morphological descriptions are used in Speight (1990). In this report, channels are excluded as a category, because river and stream channels are not considered to be wetlands under the Victorian definition. Categories for marine and estuarine wetlands are added.

Wetland origin

A wetland's geomorphic origin is likely to also reflect the ongoing physical and biological processes, eg compare a basin in a floodplain from one formed in a volcanic crater. The wetland origin attribute thus provides a context for the wetland morphology. Geomorphic origin categories have been adapted from Paijmans *et al.* (1985), Speight (1990) and Riley *et al.* (1984).

Water regime

The frequency and duration of flooding is one of the major determinants of a wetland's species composition. Inland wetlands range from permanently flooded to episodically flooded areas. Marine wetlands have varying degrees of tidal and runoff influence. The water regime categories used here are modified from those of Paijmans *et al.* (1985) and primarily reflect flooding frequency.

Salinity/conductivity

Conductivity is a major determinant of wetland ecology. Barson (1984) found that conductivity and salinity contributed to the discrimination between the 60 Victorian wetlands sampled both in terms of water chemistry groupings and independent macrophytic vegetation groupings. Many inland wetlands are naturally saline due to salt deposited from past marine environments and high levels of evaporation relative to water flow through the wetland. Wetlands are also becoming salinised due to human activities (or salinity mitigation measures). Wetland organisms tolerate a greater or lesser range of salinities, depending on the species; however, as salinity increases the number of tolerant organisms decreases.

Electrical conductivity (EC) is a measure of the ease with which an electrical current will pass through a solution. For simple sodium chloride solutions, EC is directly related to the salinity measurement of total dissolved solids (TDS), which is measured in grams of salt per kilogram (or parts per thousand). While most natural waters contain a more complex mix of ions, EC is still useful as a measure of total solute concentration (Manning 1987; Williams 1986). If only one measurement of salinity is to be made, EC is the most useful.

EC cannot be precisely converted to salinity (TDS) measurements unless information is available on the proportions of the different ions in the water (Williams 1986; Drever 1982). Williams (1986) calculated the relationship between conductivity and the salinity of Australian saline lakes, based on samples from lakes in Western Australia, South Australia and Victoria. This relationship was used to convert salinity measurements to equivalent EC classes for inland saline wetlands.

The salinity/conductivity classes provided cannot be distinguished on the basis of only one measurement in the absence of some knowledge of seasonal fluctuations in water level or tidal influence. The number of measurements required to allocate a wetland to a class depends on the amount and regularity of variation in salinity experienced by a wetland. Ideally, repeated measurements over time will build up sufficient certainty to allow categorisation.

PH varies in freshwater wetlands from acidic to alkaline, depending on the salinity, underlying rock type or inputs such as organic matter. Barson (1984) found that pH contributed to the discrimination between wetland types within the Victorian wetlands and was related to differences in macrophytic vegetation.

Turbidity and water colour

Turbidity and water colour have not been included in the ecological classification at this stage, mainly because turbidity varies very much on a day-to-day basis depending on recent rainfall and general weather conditions. Nevertheless, turbidity and water colour indicate true differences between wetland types, as some wetlands are typically turbid or highly coloured (eg from tannin). Turbidity and water colour are included in the wetland field survey form and the Regional Wetland Database and, given repeat visits to wetlands, could be included in the ecological classification in the future.

2.4.4 The minimum data set for Victoria

The attributes for ecological classification (above) are the basis for the Victorian minimum data set.

The Victorian minimum data set (Table 20 is the absolute minimum amount of information required on every wetland.

Table 2f The Victorian Minimum Data Set

Wetland Identification and Location [1]	
Map Number	Number of the AUSLIG 1:10000 Map Series on which the wetland centre falls
Australian Map Grid (AMG) Reference	AMG Reference of the approximate centre of the wetland (as allocated by Andrew Corrick, ARI)
Wetland status and area	
Land status	Actual land status of the wetland
Area	Area of the wetland in its current state (ha)
Ecological classification attributes	
System	Inland or Marine
Biophysical region	Geomorphic Unit (Jenkin and Rowan 1986) within which the wetland falls
Morphology	Basic wetland shape
Origin	Geomorphic origin of the wetland
Water regime	Frequency and duration of flooding
Conductivity	Surface water conductivity (mS cm^{-1})/Salinity (EC)
pH	Surface water pH

The minimum data set is required in order to:

- identify the wetland (location and unique identifier);
- know its status (land tenure and conservation status) and size; and
- classify it into a broad ecological type.

---

[1] Victorian wetlands have been assigned a unique code comprising their Map no. and AMG reference (as described in the table) by Corrick, ARI. Thus, these attributes represent both location and unique identifier information.

Thus, from the minimum data set, information can be obtained on the status of wetlands in Victoria and, in particular, on the underlying goal of conservation—achieving the protection of representatives of all wetland types.

2.5 STANDARD PROCEDURE FOR BASIC WETLAND SURVEY

2.5.1 Objectives of standard wetland survey

The basic wetland survey methods outlined here are designed to collect:

- the minimum data set information and thus enable ecological classification; and
- additional information to further describe and characterise the present condition of the wetland.

Collecting this information following standard procedures will lead to consistency in all projects and the further compilation of the state-wide inventory.

2.5.2 The wetland field survey form

The wetland field survey form (Appendix 2b) was designed to hold the basic wetland survey information collected during *one* field visit. The vegetation description, water level and water chemistry measurements and the accompanying map should be retained as a record of the state of the wetland on that day. Further visits, particularly at different times of the year, will build up a picture of the wetland's dynamics and, over time, long-term and seasonal changes will be obvious.

Some of the data can be entered into the Regional Wetland Database. The exception is information which varies with time, seasonally or from day to day.

Staff may have reason to carry out more detailed surveys than the basic one outlined here for management plans, water quality monitoring, species management or rehabilitation. The wetland field survey form is not designed to take the place of those surveys, but to become a standard component of the more detailed surveys so that the benefits of a consistent approach are not lost.

As far as possible, survey techniques and standards have been derived from existing standards, such as *The Australian Soil and Land Survey Field Handbook* (second edition) (McDonald *et al.* 1990), subsequently referred to as the Field Handbook. A useful companion volume is *The Australian Soil and Land Survey Handbook: Guidelines for conducting survey* (Gunn *et al.* 1988), which discusses the background to the concepts in the Field Handbook.

Instructions for completing the wetland field survey form are given in Appendix 2c. Codes required to complete the form are given in Appendix 2d. Appendix 2e contains definitions of terms and attributes used in the ecological classification and vegetation description.

2.6 CONCLUSIONS

Wetland conservation and management require a systematic approach to survey, inventory and classification, as a prelude to evaluation, management and monitoring. Emphasis has been given to developing a standard system of data collection to ensure maximum consistency across studies and staff. An assessment of the adequacy of wetland conservation and management in Victoria can only be undertaken with a state-wide inventory and ecological classification scheme. A Regional Wetland Database has been developed to store most of the information and to make that information available to staff.

In accordance with the nation-wide approach, the Victorian minimum data set is considered to be those attributes of a wetland which provide information on the wetland's location, identity, status (land tenure and conservation), area and ecological type.

The ecological classification system has been based on attributes which are generally considered important in determining a wetland's ecological character; namely biophysical region, geomorphology, hydrology and water chemistry, within either a marine or an inland system. A check list of attributes is provided.

While the attributes used in the ecological classification reflect those generally in use (or recommended), there has been virtually no research testing the usefulness of the various classifications in use in Australia. Testing is necessary to determine if the attributes and categories selected for the classification scheme actually result in ecologically meaningful wetland classes, so that wetlands are ecologically similar to others in their dass, and ecologically distinctive from wetlands in other classes.

For these reasons the ecological classification scheme developed for Victorian wetlands must be tested. The classification scheme is designed to be flexible to changes (such as additional or merged classes) if the necessity for such changes is demonstrated.

The wetland field survey form contains, in addition to the essential minimum data set, descriptive information relating to hydrology, the condition of the wetland, uses, vegetation and water chemistry. This information is designed to provide a basic description of the wetland. It is recommended that staff undertaking more detailed surveys collect the basic information for the Regional Wetland Database as part of their more comprehensive data collection.

2.7 REFERENCES

Austin, M.P. and Margules, C.R. 1986. Assessing representativeness. In Usher, M.B. (ed.). Wildlife conservation evaluation. Chapman and Hall, London, pp 45-67.

Australian National Parks and Wildlife Service and Bureau of Rural Resources Undated. Wetland Inventory: towards a national approach. Summary statement for Technical Workshop hosted by the Bureau of Rural Resources and the Australian National Parks and Wildlife Service, Canberra, August 5-6,1991.

Australian Nature Conservation Agency 1993. Directory of Important Wetlands in Australia. Australian Nature Conservation Agency, Canberra.

Barson, M.M. 1984. Numerical analyses of macrophyte vegetation in Victorian wetlands in relation to environmental factors. Unpublished PhD Thesis, Botany Department, University of Melbourne.

Barson, M.M. and Williams, J.E. 1991. Wetland inventory—towards a unified approach. Draft discussion paper for Technical Workshop hosted by the Australian National Parks and Wildlife Service and the Bureau of Rural Resources, Canberra, August 5-6,1991.

Beilharz, M.I. 1990. The Wetland Survey Form and Supplementary Information for the Scientific Committee (Draft). Unpublished report, Department of Conservation and Environment, Melbourne.

Beilharz, M.I., Payne, D. and Richardson, K. 1993. Regional Wetland Database User Manual. Wetlands Conservation Report Series No.5. Department of Conservation and Natural Resources, Melbourne.

Blackhall, S.A. 1986. A survey to determine waterbird usage and conservation significance of selected Tasmanian wetlands. Occasional Paper No. 14, National Parks and Wildlife Service, Tasmania.

Corrick, A.H. 1981. Wetlands of Victoria. II. Wetlands and waterbirds of South Gippsland. Proc. R. Soc. Vict., 92:187-200.

Corrick, A.H. 1982. Wetlands of Victoria. III. Wetlands and waterbirds between Port Phillip Bay and Mount Emu Creek. Proc. R. Soc. Vict., 94:9-87.

Corrick, A.H. and Cowling, S.J. 1975. A survey of the wetlands of Kerang, Victoria. Victoria Fish. Wildl. Div., Wildl. Pap. No. 5.

Corrick, A.H. and Cowling, S.J. 1978. A survey of wetlands in the Lake Cooper area, Victoria. Victoria Fish. Wildl. Div., Wildl. Pap. No. 17.

Corrick, A.H. and Norman, F.I. 1980. Wetlands of Victoria. I. Wetlands and waterbirds of the Snowy River and Gippsland Lakes catchments. Proc. R. Soc. Vict. 91:1-15.

Cowardin, L.M., Carter, V., Golet, F.C. and La Roe, E.T. 1979. Classification of wetlands and deepzvater habitats of the United States. Fish and Wildlife Service US Department of the Interior, Washington, DC.

Department of Conservation, Forests and Lands, Water Victoria and Ministry for Planning and Environment 1988. Wetlands Conservation Program for Victoria. Government of Victoria, Melbourne.

Donohue, R. and Phillips W. (eds) 1991. Educating and managing for wetlands conservation. Proceedings of the Wetlands Conservation and Management Workshop, University of Newcastle and The Wetlands Centre, Shortland, 11-15 February, 1991. Australian National Parks and Wildlife Service.

Drever, J.T. 1982. *The Geochemistry of natural waters.* Prentice-Hall Inc., Englewood Cliffs, N.J.

Dugan, P.J. (ed.) 1988. *Wetland conservation: a review of current issues and required action.* IUCN, Gland, Switzerland.

Gunn, R.H., Beattie, J.A., Reid, R.A. and van de Graaff, R.H.M. (eds) 1988. *Australian Soil and Land Survey Handbook: Guidelines for conducting surveys.* Inkata Press, Melbourne.

Hart, B.T. 1974. A compilation of Australian water quality criteria. *Australian Water Resources Council Technical Paper No. 7.* Australian Government Publishing Service, Canberra.

Jenkin, J.J. and Rowan, J.N. 1988. Geomorphic Units of Victoria—Map Set. In Land Conservation Council *Statewide assessment of public land use.* Victorian Government Printing Office, Melbourne.

Larson, J.S. (ed.) 1976. *Models for evaluation for freshwater wetlands.* University of Massachusetts, Amherst.

Lind, O.J. 1979. *Handbook of common methods in Limnology.* Second edition. Mosby, St Louis, Missouri.

Manning, J.C. 1987. *Applied principles of hydrology.* Merrill Publishing Co. Columbus, Ohio.

McComb, A.J. and Lake, P.S. (eds) 1988. *The conservation of Australian wetlands.* Surrey Beatty and Sons, Chipping Norton, NSW.

McDonald. R.C., Isbell, R.F., Speight, J.G., Walker, J. and Hopkins, M.S. 1990. *Australian Soil and Land Survey Field Handbook.* Second edition. Inkata Press, Melbourne.

Newton, M. In prep. *Evaluation of Victoria's wetlands.* Wetlands Conservation Report Series, Department of Conservation and Natural Resources, Melbourne.

Nilsson, C. 1986. Methods of selecting lake shorelines and nature reserves. *Biological Conservation* 35:269-291.

Norman, F.I. and Corrick, A.H. 1988. Wetlands in Victoria: a brief review. In A.J. McComb and P.S. Lake (eds). *The conservation of Australian wetlands.* Surrey Beatty and Sons, Chipping Norton, NSW, pp 17-34.

Paijmans, K., Galloway, R.W., Faith, D.P., Fleming, P.M.,. Haantjens, H.A., Heyligers, P.C., Kalma, J.D. and Löffler, E. 1985. Aspects of Australian wetlands. *CSIRO Division of Water and Land Resources Technical Paper No.* 44. CSIRO, Melbourne.

Peterken, G.F. 1968. International selection of areas for reserves. *Biological Conservation* 1:55-61.

Pressey, R.L. and Adam, P. In press. A review of wetland inventory and classification in Australia. *Vegetation.*

Pressey, R.L. and Bedward, M. 1991. Inventory and classification of wetlands: what for and how effective? In W. Phillips and R. Donohue (eds). *Educating and Managing for Wetlands Conservation.* Proceedings of the Wetlands Conservation and Management Workshop, University of Newcastle and The Wetlands Centre, Shortland, 11-15 February, 1991. Australian National Parks and Wildlife Service, pp 190-197.

Pressey, R.L. 1984. A method for description and evaluation of coastal floodplain wetland. In K. Myers, C.R. Margules and I. Musto (eds). Survey methods for nature conservation Volume 1. CSIRO, Canberra, pp 275-303.

Pressey, R.L. 1986. Wetlands of the River Murray below Lake Hume. River Murray Commission Environmental Report 86/1.

Riley, S.J., Warner, R.R. and Erskine, W. 1984. Classification of water bodies in New South Wales. NSW Water Resources Commission, Sydney, pp 15-51.

Rowan, J. 1990. Land systems of Victoria. Department of Conservation and Environment and Land Conservation Council, Melbourne.

Semeniuk, C.A. 1987. Wetlands of the Darling system - a geomorphic approach to habitat classification. Journal of the Royal Society of Western Australia 69:95-112.

Semeniuk, C.A. and Semeniuk, V. In press. A geomorphic approach to global wetland classification. Vegetation.

Speight, J.G. 1990. Landform. In McDonald. R.C., Isbell, R.F., Speight, J.G., Walker, J. and Hopkins, M.S. Australian Soil and Land Survey Field Handbook. Second edition. Inkata Press, Melbourne, pp 9-57.

Stanton, J.P. and Morgan, G. 1977. The rapid selection and appraisal of key and endangered sites: the Queensland case study. School of Natural Resources, University of New England, Armidale. Report No. PR4.

Stone, A. 1991. Economic evaluation of wetlands. Wetlands Conservation Report Series No.1, Department of Conservation and Natural Resources, Melbourne.

Walker, J. and Hopkins, M.S. 1990. Vegetation. In McDonald. R.C., Isbell, R.F., Speight, J.G., Walker, J. and Hopkins, M.S. (eds). Australian Soil and Land Survey Field Handbook. Second edition. Inkata Press, Melbourne, pp 58-86.

Williams, W.D. 1986. Conductivity and salinity of Australian Salt Lakes. Aust. J. Mar. Freshw. Res. 37:177-182.

2.9 APPENDICES

Appendix 2a Wetland classification schemes used in other states and territories

(i) Australian classification of wetlands from Paijmans et al. *(1985)*

<u>I Lakes:</u> (areas of open water generally over 1 m deep with little or no persistent emergent vegetation)

1 Permanent and near permanent lakes

a Permanent floodplain lakes including billabongs and waterholes in channels
Permanent lakes of coastal dunes and beach ridge plains
• Permanent lakes in terminal drainage basins
Permanent lakes associated with lava flows
• Permanent crater lakes
Permanent karst lakes
Permanent glacial lakes
Permanent man-made lakes

2 Seasonal lakes (alternately wet and dry every year according to season)

a Seasonal floodplain lakes
Seasonal lakes in terminal drainage basins

3 Intermittent lakes (alternately wet and dry but less frequently and regularly than seasonal lakes)

a Intermittent floodplain lakes
Intermittent coastal dune lakes
• Intermittent lakes in terminal drainage depressions
Intermittent man-made lakes

4 Episodic lakes (dry most of the time with rare and very irregular wet phases)

a Episodic lakes in terminal drainage depressions
Episodic lakes on present or former floodplains (other sub-classes are rare or non-existent)

<u>II Swamps:</u> (dominantly vegetated; where present water generally less than 1 m deep; persistent emergent vegetation)

1 **Permanent swamps (wet most of the time)**

a Permanent floodplain swamps
Permanent swamps of coastal dunes and beach ridge plains
• Permanent swamps in terminal drainage depression
Permanent swamps associated with lava flows
• Permanent crater swamps
High-mountain permanent swamps
Permanent swamps fed by springs

These swamps can be further subdivided according to vegetation into herbaceous, sedge, heath and scrub, woodland and forest, and sphagnum types.

2 Seasonal swamps (seasonally wet and dry each year)

a Seasonal floodplain swamps
(Other sub-classes rare or absent)

3 Intermittent swamps (alternately, but irregularly, wet and dry)

a intermittent floodplain swamps
Intermittent swamps in terminal drainage depressions

4 Episodic swamps (rarely contain water and lacking swamp vegetation)

(Rare, no sub-classes distinguished)

III Land subject to inundation : (water not present long enough for typical wetland vegetation to develop, but may be important waterbird habitat)

1 **Seasonally inundated**
  - a Floodplains
  - b River and creek banks

2 **Intermittently inundated**
  - a Floodplains
  - b River and creek banks

IV River and creek channels

1 **Permanent and near-permanent channels**
  - a Rocky
  - b Sandy
  - c Silty/clayey

2 **Seasonal channels**
  - a Rocky
  - b Sandy
  - c Silty/clayey

3 **Intermittent channels**
  - a Rocky
  - b Sandy
  - c Silty/clayey

4 **Episodic channels**
  - a Rocky
  - b Sandy
  - c Silty/clayey

V Tidal flats

1 **Daily tidal flooding**
  - a Intertidal flats of open coasts
  - b Intertidal estuarine flats
  - c Intertidal stream banks

2 **Spring tidal and less frequent flooding**
  - a Supratidal surfaces
  - *b* Supratidal stream banks
  - c Saline pools

3 **Spring tidal and less frequent flooding combined with seasonal freshwater flooding**
  - a Supratidal flats
  - b Brackish pools and billabongs

VI Coastal water bodies

1 **Permanently open to the sea**
  - a Saline to brackish estuaries and inlets

2 **Intermittently open to the sea**
  - a Saline to brackish lagoons

3 **Rarely open to the sea**
  - a Brackish to fresh lagoons and lakes

(ii) Classification hierarchy of wetlands and deepwater habitats, showing systems, subsystems and classes, from Cowardin et al. *(1979).*

System	Subsystem	Class
Marine	Subtidal	Rock bottom Unconsolidated bottom Aquatic bed Reef
	Intertidal	Aquatic bed Reef Rocky shore Unconsolidated shore
Estuarine	Subtidal	Rock bottom Unconsolidated bottom Aquatic bed Reef
	Intertidal	Aquatic bed Reef Streambed Rocky shore Unconsolidated shore Emergent wetland Scrub-shrub forest Forested wetland
Riverine (Wetlands and deepwater habitats contained within a channel, except where wetlands are dominated by vegetation (palustrine) or salinity from ocean-derived salts is greater than 0.5_ (estuarine)).	Tidal	Rock bottom Unconsolidated bottom Aquatic bed Rocky shore Unconsolidated shore Emergent wetland (non-persistent)
	Lower perennial	Rock bottom Unconsolidated bottom Aquatic bed Rocky shore Unconsolidated shore Emergent wetland (non-persistent)
	Upper perennial	Rock bottom Unconsolidated bottom Aquatic bed Rocky shore Unconsolidated shore
	Intermittent	Streambed

System	Subsystem	Class
Lacustrine (basin wetlands lacking trees, shrubs or other vegetation and area over 8 ha)	Limnetic (over 2 m deep)	Rock bottom Unconsolidated bottom Aquatic bed
	Littoral (shore to depth of 2 m)	Rock bottom Unconsolidated bottom Aquatic bed Rocky shore Unconsolidated shore Emergent wetland
Palustrine (Nontidal wetlands dominated by trees, shrubs or other vegetation; or tidal wetlands where: area is less than 8 ha, active wave-formed or bedrock shoreline features lacking, water depth no more than 2 m at low water and salinity due to ocean-derived salts less than 0.5_)		Rock bottom Unconsolidated bottom Aquatic bed Unconsolidated shore Moss-lichen wetland Emergent wetland Scrub-shrub wetland Forested wetland

(iii) Wetland types of Semeniuk and Semeniuk (in press)

Primary wetland categories

Water Longevity	**Landform**				
	Basin	**Channel**	**Flat**	**Slope**	**Highland**
Permanent inundation	lake	river	-	-	-
Seasonal inundation	sumpland	creek	floodplain	-	-
Intermittent inundation	playa	wadi	barlkarra		-
Seasonal waterlogging	dampland	trough	palusplain	paluslope	palusmont

Criteria used to develop secondary wetland categories:

- Water salinity
- Consistency of water salinity
- Size
- Plan shape

i(v) Ramsar classification of wetland types, as slightly modified for use in A Directory of Important Wetlands in Australia *(Australian Nature Conservation Agency 1993).*

A. MARINE AND COASTAL WETLANDS

1 Marine waters—permanent shallow waters less than six metres deep at low tide; includes sea bays, straits.
2 Subtidal aquatic beds; includes kelp beds, sea-grasses, tropical marine meadows.
3 Coral reefs.
4 Rocky marine shores; includes rocky offshore islands, sea cliffs.
5 Sand, shingle or pebble beaches; includes sand bars, spits, sandy islets.
6 Estuarine waters; permanent waters of estuaries and estuarine systems of deltas.
7 Intertidal mud, sand or salt flats.
8 Intertidal marshes; includes salt-marshes, salt meadows, saltings, raised salt marshes, tidal brackish and freshwater marshes.
9 Intertidal forested wetlands; includes mangrove swamps, nipa swamps, tidal freshwater marshes.
10 Brackish to saline lagoons with one or more relatively narrow connections with the sea.
11 Freshwater lagoons and marshes in the coastal zone; includes delta lagoon and marsh systems.

B INLAND WETLANDS

1 Permanent rivers and streams; includes waterfalls.
2 Seasonal and irregular rivers and streams.
3 Inland deltas (permanent).
4 Riverine floodplains; includes river flats, flooded river basins, seasonally flooded grassland, savanna and palm savanna.
5 Permanent freshwater lakes (>8 ha); includes large oxbow lakes.
6 Seasonal/intermittent freshwater lakes (>8 ha), floodplain lakes.
7 Permanent saline/brackish lakes.
8 Seasonal/intermittent saline lakes.
9 Permanent freshwater ponds (<8 ha), marshes and swamps on inorganic soils; with emergent vegetation waterlogged for at least most of the growing season.
10 Seasonal/intermittent freshwater ponds and marshes on inorganic soils; includes sloughs, potholes, seasonally flooded meadows, sedge marshes.
11 Permanent saline/brackish marshes.
12 Seasonal saline marshes.
13 Shrub swamps; shrub-dominated freshwater marsh, shrub, carr, alder thicket on inorganic soils.
14 Freshwater swamp forest; seasonally flooded forest, wooded swamps; on inorganic soils.
15 Peatlands, forest, shrub or open bogs.
16 Alpine and tundra wetlands; includes alpine meadows, tundra pools, temporary waters from snow melt.
17 Freshwater springs, oases.

18 Geothermal wetlands

19 Inland, subterranean karst wetlands

C HUMAN-MADE WETLANDS

1 Water storage areas; reservoirs, barrages, hydro electric dams, impoundments (generally >8 ha).

2 Ponds, including farm ponds, stock ponds, small tanks (generally < 8 ha).

3 Aquaculture ponds; fish ponds; shrimp ponds.

4 Salt exploitation; salt pans, salines.

5 Excavations; gravel pits, borrow pits, mining pools.

6 Wastewater treatment; sewage farms, settling ponds, oxidation basins.

7 Irrigated land and irrigation channels; rice fields, canals, ditches.

8 Seasonally flooded arable land, farm land.

9 Canals

APPENDIX 2b WETLAND FIELD SURVEY FORM (p.1)

Asterisked fields are contained in the Regional Wetland Database; attributes in bold comprise the wetland classification. Fill in spaces or circle correct option(s).

REFERENCE INFORMATION ('Location' data screen- Regional Wetland Database)

Date ---- --- Time — — — Surveyor name - - - - - - - - - - - - Phone (----)--------
Wetland name
*Wetland system
*Map number *AMG reference ------------ --------------
*Local reference - - - - - - - - - - *LCC reference (public land only)

BIOPHYSICAL ATTRIBUTES ('Attributes' data screen—Regional Wetland Database)

***Artificial?** 1 (artificial) / 0 (natural) Attitude (m)

GEOMORPHOLOGY

***System:** Inland / Marine ***Geomorphic unit(s)** - - - - -– –
***<u>Morphology</u>** ***<u>Origin</u>**
<u>Inland system</u>
SBA / DBA OXB / WHO / DEP / PSD / LAV / CRA / VOL / SOL / COL / TDB / FAU / SIN
MET / CDU / RDU / ODU / DEF / SPR / GLA / IMP / SEW / SEB / PIT
FLA FLP
SLO BAN / HIL
HIG MOU
<u>Marine System</u>
TID RRE / MUD
EST EST

HYDROLOGY

***Water regime:** <u>Inland system:</u> PER / SMP / SEA / INT / EPR / DRY/
<u>Marine system:</u> ITF / STF / SFF

***Water source(s):** LOC / CHA / OFF / STR / IRR / GRW / SPR / MAR
<u>Inland systems:</u>
*Maximum depth - - - - m (when full) *Average depth - - - - m (when full)
*G/water depth - - - - - - - m (average) % Cover (area of water relative to full)

SURFACE WATER CHEMISTRY (<u>category code</u> based on field data recorded on page 2)

***Conductivity/Salinity**

Inland systems	EC (mS^{-1})	TDS ( )	Marine systems	TDS (_)
1 Fresh	<5.5	<3	10 Brackish	3-10
2 Slightly saline	5.5-16.5	3-10	11 Mixohaline	10–30
3 Saline	16.5-60	10-40	12 Euhaline	30-40
4 Hypersaline	>60	>40	13 Hyperhaline	>40
5 Fresh—slightly saline	<5.5-16.5	<3-10	14 Fresh—euhaline	<3-40
6 Fresh—saline	<5.5-60	<3-40	~~15 Brackish—euhaline~~	3-40
7 Slightly saline—saline	5.5-60	3-40	16 Brackish--hyperhaline	3 ->40
8 Slightly saline—hypersaline	5.5->60	3->40	17 Euhaline—hyperhaline	30->40
9 Saline—hypersaline	16.5->60	10->40		

*pH: 1 Acidic (<6) 2 Neutral (6-8) 3 Alkaline (>8)
*Secchi depth: 1 Very clear (>100 cm) 2 Quite clear (50-100 cm) 3 Slightly turbid (20-50 cm) 4 Very turbid (<20 cm)
*Water colour: 1 Green/blue (low turbidity) 2 Tea coloured (tannin, low turbidity) 3 Brown (muddy)
*G/water conductivity: 1 / 2 / 3 / 4 / 5 / 6 / 7/8 / 9 (see categories for inland surface water conductivity, above)

WETLAND FIELD SURVEY FORM (p.2)

(Map number -------------- AMG reference ------- - —— Date ---

CONDITION (code and description) **AND USES**
*Habitat mod.—(0-9)/
*Hydrological mod. NATural/UNNatural
*Wetland use(s)
*Catchment use(s): FORested/GRAssland/CROpped/URBan/INDustrial (prevailing land use)

VEGETATION DESCRIPTION (attach a sketch map showing vegetation zones)
Surrounding vegetation
Description of vegetation zones

No	%A	Str	Gr	Ht	Coy	Dominant spp.	Comments
	—	—				—	
						—	________
—						—	________
				—		—	________
				—		—	________
						—	________
						—	________
	—					—	________
—				—		—	________
				—		— —	________
				—		—	________
				—		—	________

WATER CHEMISTRY (record actual measurements here; indicate collection site(s) on sketch map)

Weather conditions

Previous rainfall

Site	Time	Water depth(cm)	Reacing depth(cm)	Cond EC	Salinity ppt	pH	Temp (-C)	Secchi depth	Water colour
– – –	– – –	– – – –	– – – –	– – –	– – –		– – – .	....	– – – .
– – –	– – –	– – – –	– – – –	....	– – –		– – – .	— — -	– – – .
– – –	– – –	– – – –	– – – –	....	– – –		– – – .	– – –	– – – .
– – –	– – –	– – – –	– – – –	– – –	– – –		– – – .	– – –	– – – .
– – –	– – –	– – – –	– – – –	– – –	– – –		– – – .	– – –	– – – .
– – –	– – –	– – – –	— — —	– – –	– – –		– – – .	– – –	....
– – –	....	– – – –	....	– – –	....		....	— — -	– – – .

APPENDIX 2C INSTRUCTIONS FOR COMPLETING THE WETLAND FIELD SURVEY FORM

The attributes to be entered onto the Wetland Field Survey Form are defined and instructions for completing the form given. Refer to Appendix 6 for a list of codes which are used on the Form, and to Appendix 7 for definitions of classification attributes and vegetation description terms. For field work, Appendix 6 can be photocopied, cut out and fitted into the plastic Wildlife Atlas folders.

Attributes which should be entered in the Regional Wetland Database are marked with an asterisk. Minimum Data Set fields are shown in bold.

Wetland Field Survey Form (p.1)

Reference Information

The reference information fields marked with an asterisk should be entered into the Location details data screen of the Regional Wetland Database

Date:	Date of field visit: day, month, year, eg 12 07 93 for 12 July 1993. The date of the visit will be important in the interpretation of vegetation, soil and water data, and for comparison with data collected on subsequent visits.
Time:	Time of day to nearest hour in 24 hour clock, eg 0900 for 9am, 1500 for 3pm. The time of day may affect some data, eg dissolved oxygen (if measured).
Surveyor name:	Name of the surveyor. This allows contact to be made with the surveyor if information requires checking.
Phone:	Contact phone number, including area code.
***Wetland name:**	Name of wetland, preferably the official name from Vic Roads Gazetteers.
***Wetland system:**	**Official** or local name of wetland system (eg Barmah Forest). Linking wetlands together with a common system name in the database allows queries to be performed on an entire system.
***Map number:**	Number of the 1:100 000 topographic NATMAP (now AUSLIG) map sheet.
***AMG reference:**	Easting (numbers at the top and bottom of map) and northing (numbers at side) of wetland. ***NOTE:** Always use the Map Number and AMG Reference assigned by Andrew Corrick, ARI. This is the unique identifier of each wetland. It will already be entered into the Regional Wetland Database.*
***Local reference:**	Users may enter a reference code specific to their project (optional).
***LCC reference:**	Reference code for site from LCC recommendations (public land only). Note that LCC reference codes are repeated in different LCC regions, hence it is possible that the same LCC reference code is used for more than one wetland within a NRE region (and almost certainly within NRE areas).

Biophysical Attributes

The biophysical attributes fields marked with an asterisk should be entered into the Attributes data screen of the Regional Wetland Database.

***Artificial:**	Circle 1 if the wetland is artificial; 0 if natural. Artificial wetlands include reservoirs and dams etc. which occur on a site which did not previously support a wetland and wetlands whose structure or water regime have been heavily modified, eg through damming or input of irrigation water. Information has not been entered into this field for all wetlands. However, as this field cannot be edited, users must contact Andrew Corrick with any updated information.
***Altitude:**	The altitude of the water surface when full in metres above sea level.

Geomorphology

***System:**	Inland or Marine. Wetlands are considered part of the marine system if they receive some water of marine origin, eg tidal flats or estuaries. Coastal wetlands which obtain their water from solely from surface runoff, river channels or groundwater are not considered marine wetlands, nor are coastal lakes which have lost an earlier connection with the sea.

For a number of the attributes below, different categories are used for inland and marine wetlands.

***Geomorphic Unit:**	Two-digit number for geomorphic unit of Jenkin and Rowan (1988) and Rowan (1990). The geomorphic unit of the approximate centre of the wetland is loaded on to the database from the GIS. Geomorphic unit is not a characteristic which will be determined in the field, however it is included on the Wetland Field Survey Sheet so that all of the attributes required for wetland classification are on the sheet.
***Morphology:**	Circle the appropriate code for basic morphology (landform) of the wetland.
***Origin:**	Circle the appropriate code for geomorphic origin of the wetland. If more than one process has lead to the formation and presence of a wetland, select the most important one.

Hydrology

***Water regime:**	Circle the appropriate code for water regime. Water regime categories are designed to describe the prevailing regime, so information on past water levels is required.
***Water source(s):**	Circle the appropriate code for water source. As water may enter the wetland from a number of different sources, there is space for up to 4 occurrences.
***Maximum depth:**	Maximum depth (m) of the wetland when full. To determine this, the deepest part of the wetland must be identified and measured. Such information is available for some wetlands.
***Average depth:**	Approximate or prevailing depth (m) of the wetland when full. This allows the user to enter a depth measurement describing the prevailing conditions without having ascertained the exact depth or location of the deepest part.
***G/water depth:**	Depth (m) of the groundwater below the surface at the wetland edge.
% Cover:	Proportion of the area of the wetland which is currently covered by water, relative to when the wetland is 'full' (ie when it almost overflows the banks). In times of flood, the wetland may be over 100% of normal 'full' condition, indicate by 100+.

Surface Water Chemistry

NOTE: The actual readings are recorded on page 2. The fields in the database, however, ask for a broad categorisation of the wetland rather than specific readings. Hence, the field entries represent the prevailing category (or range) within which a wetland falls.

***Conductivity:**	Circle the appropriate number for salinity/conductivity category.
***pH:**	Circle the appropriate number for pH category.
***Secchi depth:**	Circle the appropriate number for Secchi depth category.
***Colour:**	Circle the appropriate number for water colour.
***G/water cond.:**	Circle the appropriate number for groundwater conductivity category.

Wetland Field Survey Form (p.2)

Condition and Uses

***Habitat mod.:**	Habitat modification: enter the number for degree of alteration of the habitat (categories from McDonald *et al.* (1990)) There is space for a brief description of the type of modification.
***Hydrological mod:**	Circle NAT(ural) if hydrologically unmodified, UNN(natural) if modified. There is space for a brief description of the type of modification.
***Wetland use(s):**	Enter the appropriate code/s for uses of the wetland itself (up to 4 occurrences).
***Catchment use(s):**	Circle the appropriate three-character code to broadly characterise the land use in the wetland's catchment (up to 2 occurrences).

Vegetation Description

The vegetation within the normal full supply level of the wetland is described in terms of structure and dominant species. The vegetation description is based on the guidelines in the Vegetation chapter in the Field Handbook (Walker and Hopkins, 1990) with additional terms used here to describe aquatic plants. It is summarised below, and the fields are defined.

Vegetation zones

Include a diagrammatic sketch of the wetland (see Figure 2) showing the boundaries of the vegetation zones within the wetland. Number the zones on the sketch, this will correspond to the entry in the first column labelled 'No'. Open water or bare ground are also a zone (although containing no vegetation). The % area of each habitat type within the wetland will be entered in the second column.

Strata

Vegetated zones will have up to three strata or layers, eg submerged aquatic plants, reeds and trees. Within each vegetation zone, the growth form, height and cover of <u>each stratum</u> are described (the aquatic stratum is described in less detail than terrestrial or emergent strata). Therefore, a zone with three strata will take three lines to describe. Also, the names of the dominant species (by area covered) may be recorded and comments made.

Surrounding vegetation:	Describe the vegetation immediately surrounding the wetland itself.
No:	Give the number of the habitat type as labelled on the accompanying wetland sketch (1,2,3 etc.)
	% Area: estimate the area of each zone as a percentage of the total wetland area (when full).
Str:	Stratum: identify the stratum which is being described on that line as either Highest, Middle, Lowest or Aquatic. H, M and L should be used for terrestrial and emergent vegetation. These are relative terms which do not infer a particular height (which is recorded separately). A should be used for aquatic vegetation which is predominantly submerged or floating.
Growth:	Describe the growth form using the terms described in the Field Survey Codes for either aquatic or emergent/terrestrial strata. Aquatic strata with mixed species may require more than one term.
Height:	Give the predominant height of that stratum (not of a few emergents) by the code for the height class [See Field Survey Codes] <u>**or**</u> give the height in metres. Ensure that the code letters are easily distinguishable from actual height measurements in numbers (Not required for aquatic growth forms).
Cover:	Give the cover class of the crown (for trees and shrubs) or ground cover (for lowest stratum). [See Field Survey Codes]
Dominant species:	List the dominant species (up to three) if they can be accurately identified. Give the first two letters of the genus and the first three letters of the specific epithet, eg *Eucalyptus camaldulensis* would be recorded as EUCAM. If identification can only be made to genus level write, eg *Juncus sp.* in the Comments column. If it is not possible to identify genera, write a general description such as mixed grasses.
Comments:	Add any descriptive comments on the vegetation, eg flowering, dying.

Water Chemistry

Salinity/Conductivity and **pH** are important attributes in determining the classification of wetlands. In addition to the category information entered onto page one of the form (which can be stored in the Regional Wetland Database) the raw data should also be stored.

Mark the site(s) at which you take water chemistry measurements on the sketch map (a, b, c etc.). These letters will go in the first column of the water chemistry data.

Depending on the time available and the likely variability within the wetland, measurements may be taken at a number of sites, eg near inflows or in various vegetation zones. Unless the wetland is very large, poorly mixed or stratified, measurement of the following attributes at a single site is likely to give a reasonable picture of the whole wetland.

Since clearness of the day, position of the sun and roughness of the water are all significant considerations, they should all be recorded along with the water quality data (in weather conditions). It is important for an observer to establish a standard set of operation conditions, eg always taking **Secchi depth readings** with or without glasses or sunglasses, with the sun to one's back, between 9am and 3 pm (Lind 1979).

Weather conditions:	As weather conditions can influence mixing and visibility, note whether it is overcast or sunny and the wind strength and direction.
Previous rainfall:	Previous rainfall can also influence readings of salinity and Secchi depth, hence note any recent rainfalls in the area.
Water depth:	Measure the depth of the water (in cm) at the spot at which you are taking your readings.
Reading depth:	Record the depth (in cm) at which you recorded the water chemistry measurements. In most cases this will probably *be* within 10 cm of the surface. In some cases, surveyors may wish to investigate changes in, say, salinity with depth.
Cond (EC):	Conductivity, measured in EC units (mS^{-1}) of surface water (or at specified depths).
Salinity (ppt):	Total dissolved salts, in parts per thousand of surface water (or at specified depths). (An alternative to conductivity).
pH:	pH of surface water (or at specified depths).
Temp (°C):	Apart from shallow areas and surface waters, the daily temperature variation will not be significant, therefore measurements should be taken away from shallow edges and surface waters. Conductivity meters will generally also give a temperature reading.
Secchi depth:	Secchi depth provides a quick relative measure of turbidity which affects light penetration and therefore the growing conditions for macrophytes, phytoplankton and benthos (Hart 1974). To determine Secchi disk visibility, slowly lower the disk into the water until it disappears from sight, and note this depth. Lower the disk a little further, then slowly raise it until it reappears, and note this depth. The average of these two readings is taken for the final Secchi disk visibility depth (Lind 1979). In shallow wetlands, the Secchi disk may not disappear from sight. In that case record the Secchi depth as, for instance, >40 cm (and the Water depth is also recorded as 40 cm)
Water colour:	Water colour will also affect Secchi depth measurement and will assist in interpretation. It need only be categorised into green/blue (clear), tea-coloured (brown from tannin but without suspended particles) or brown (muddy with suspended particles).
Other:	The final column is available for additional data, eg dissolved oxygen.

APPENDIX 2d FIELD INSTRUCTIONS AND CODES FOR THE WETLAND FIELD SURVEY FORM

Wetland Field Survey Form—INSTRUCTIONS (1)

Reference Information

Date:	Date of field visit: day, month, year, eg 12 07 93 for 12 July 1993.
Time:	Time of day to nearest hour in 24 hour clock, eg 0900 for 9am, 1500 for 3pm.
Surveyor name:	Name of the surveyor.
Phone:	Contact phone number, including area code.
***Wetland name:**	Name of wetland.
***Wetland system:**	Official or local name of wetland system (eg Barmah Forest).
***Map number:**	Number of the 1:100 000 topographic NATMAP (now AUSLIG) map sheet.
***AMG reference:**	Easting (numbers at the top and bottom of map) and northing (numbers at side) of wetland. *NOTE: Always use the Map Number and AMG Reference assigned by Corrick, ARI. his is the unique identifier of each wetland. It will already be entered into the Regional Wetland Database.*
***Local reference:**	Users may enter a reference code specific to their project (optional).
***LCC reference:**	Reference code for site from LCC recommendations (public land only).

Biophysical Attributes

***Artificial:**	Circle 1 if the wetland is artificial, 0 if natural.
***Altitude:**	The altitude of the water surface when full in metres above sea level.

GEOMORPHOLOGY

***System:**	Marine or Inland.
***Geomorphic Unit:**	Two-digit number for geomorphic unit of Jenkin and Rowan (1988) and Rowan (1990).
***Morphology:**	Circle the appropriate three-character code for basic morphology (landform) of the wetland.
***Origin:**	Circle the appropriate three-character code for geomorphic origin of the wetland.

Hydrology

***Water regime:**	Circle the appropriate code for water regime. Water regime categories are designed to describe the prevailing regime, so information on past water levels is required.
***Water source(s):**	Circle the appropriate code for water source. As water may enter the wetland from a number of different sources, there is space for up to 4 occurrences.
***Maximum depth:**	Maximum depth (m) of the wetland when full.
***Average depth:**	Approximate or prevailing depth (m) of the majority of the wetland when full.
***G/water depth:**	Depth (m) of the groundwater below the surface at the wetland edge.
% Cover:	Proportion of the area of the wetland which is currently covered by water, relative to when the wetland is 'full' (eg at the top of the banks). In times of flood, the wetland may be over 100% of normal 'full' condition: 100+.

Surface Water Chemistry

NOTE: The actual readings are recorded on page 2. The fields in the database, however, ask for a broad categorisation of the state of the wetland rather than specific readings. Hence, the field entries represent the prevailing category (or range) within which a wetland falls.

***Conductivity:**	Circle the appropriate number for conductivity/salinity category.
***pH:**	Circle the appropriate number for pH category.
***Secchi depth:**	Circle the appropriate number for secchi depth category.

***Colour:**	Circle the appropriate number for water colour.
***G/water cond.:**	Circle the appropriate number for groundwater conductivity category.

CONDITION AND USES

***Habitat mod.:**	Habitat modification: enter the number for degree of alteration of the habitat.
***Hydrological mod.:**	Circle NAT(ural) if hydrologically unmodified, UNN(atural) if modified. There is space for a brief description of the type of modification.
***Wetland use(s):**	Enter the appropriate code/s for uses of the wetland itself (up to 4 occurrences).
***Catchment use(s):**	Circle the appropriate three-character code to broadly characterise the land use in the wetland's catchment (up to 2 occurrences).

Vegetation Description

Include a diagrammatic sketch of the wetland showing the boundaries of the vegetation zones within the wetland. Number the zones on the sketch, this will correspond to the entry in the first column labelled 'No'. Open water or bare ground are also a zone (although containing no vegetation).

Strata

Within each vegetation zone, the growth form, height and cover of each stratum are described (the aquatic stratum which is described in less detail than terrestrial or emergent strata). Therefore, a zone with three strata will take three lines to describe.

Surrounding vegetation:	Describe the vegetation immediately surrounding the wetland itself.
No:	Give the number of the habitat type as labelled on the accompanying wetland sketch (1,2,3 etc.) % Area: estimate the area of each zone as a percentage of the total wetland area (when full).

WETLAND FIELD SURVEY FORM—INSTRUCTIONS (4)

Str:	Stratum: identify the stratum which is being described on that line as either Highest, Middle, Lowest or Aquatic. H, M and L should be used for terrestrial and emergent vegetation. These are relative terms which do not infer a particular height (which is recorded separately). A should be used for aquatic vegetation which is predominantly submerged or floating.
Growth:	Describe the growth form using the terms described in the Field Survey Codes for either aquatic or emergent/terrestrial strata. Aquatic strata with mixed species may require more than one term.
Height:	Give the predominant height of that stratum (not of a few emergents) by the code for the height class [See Field Survey Codes] **or** give the height in metres. Ensure that the code letters are easily distinguishable from actual height measurements in numbers (Not required for aquatic growth forms).
Cover:	Give the cover class of the crown (for trees and shrubs) or ground cover (for lowest stratum). [See Field Survey Codes]
Dominant species:	List the dominant species (up to three) if they can be accurately identified. Give the first two letters of the genus and the first three letters of the specific epithet, eg *Eucalyptus camaldulensis* would be recorded as EUCAM. If identification can only be made to genus level write, eg *Juncus sp*. in the Comments column. If it is not possible to identify genera, write a general description such as mixed grasses.
Comments:	Add.any descriptive comments on the vegetation, eg flowering, dying.

WATER CHEMISTRY

Mark the site(s) at which you take water chemistry measurements on the sketch map (a, b, c etc.). These letters will go in the first column of the water chemistry data.

Weather conditions:	Note whether it is overcast or sunny and the wind strength and direction.
Previous rainfall:	Note any recent rainfalls in the area.

Water depth:	Measure the depth of the water (in cm) at the spot at which you are taking your readings.
Reading depth:	Record the depth (in cm) at which you recorded the following water chemistry measurements. In most cases this will probably be within 10 cm of the surface. In some cases, surveyors may wish to investigate changes in, say, salinity with depth.
Cond (EC):	Conductivity, measured in EC units (mS^{-1}) .
Salinity (ppt):	Total dissolved salts, in parts per thousand. (An alternative to conductivity).
pH:	Water pH.
Temp (°C):	Water temperature.
Secchi depth:	Secchi depth (cm). In shallow wetlands, the Secchi disk may not disappear from sight. In that case record the Secchi depth as, for instance, >40cm (the Water depth is also recorded as 40cm)
Water colour:	Green/blue (clear), tea-coloured (brown from tannin but without suspended particles) or brown (muddy with suspended particles).
Other:	The final column is available for additional data, eg dissolved oxygen.

WETLAND FIELD SURVEY FORM—CODES, BIOPHYSICAL ATTRIBUTES, GEOMORPHIC UNIT

1,2 Central Victorian Highlands

1. East Victorian Uplands

- 1 Dissected uplands
- 2 Dissected plateau (Wellington uplands)
- 3 High plains (Dargo, Bogong etc.)

2. West Victorian Uplands

- 1 Dissected uplands (Midlands etc.)
- 2 Prominent ridges (Grampians)
- 3 Dissected tableland (Dundas Tableland)
- 4 Dissected tableland (Merino Tableland)

3. South Victorian Uplands

- 1 Dissected fault blocks (Otway Ranges)
- 2 Moderately dissected block (Barrabool Hills)
- 3 Moderately dissected ridge (Momington Pen)
- 4 Dissected fault blocks (S. Gipps. Ranges)
- 5 Dissected outlier (Wilsons Promontory)

4-6 Murray Basin Plain

4. Riverine Plain

- 1 Present floodplain (Murray Valley)
- 2 Older alluvial plain (Shepparton)

5. Mallee Dunefield

- 1 Low calcareous dunes (Ouyen)
- 2 High siliceous dunes (Big Desert, Sunset)

6. Wimmera Plain

- 1 Clay plains (Nhill)
- 2 Ridges and flats (Goroke)
- 3 Low siliceous dunes (Little Desert)

7. West Victorian Volcanic Plains

- 1 Undulating plain (Western District)
- 2 Stony undulating plain (Western District)

8. South Victorian Coastal Plains

- 1 Ridges and flats (Follett)
- 2 Dissected plain (Port Campbell)
- 3 Sand and clay pan (Moorabin)
- 4 Fans and terraces (Western Port)
- 5 Barrier complexes (Discovery Bay/Gipps L.)

9. South Victorian Riverine Plains

- 1 Present floodplains (Gippsland)
- 2 Intermediate terraces (Gippsland)
- 3 High terraces and fans (Gippsland)

WETLAND MORPHOLOGY (see definitions, Appendix 2e)

Inland systems

SBA	Shallow basin (<2m)
DBA	Deep basin (>2m)
FLA	Flat
SLO	Slope
HIG	Highland

Marine systems

TID	Tidal flat
EST	Estuary

WETLAND ORIGIN (see definitions, Appendix 2e)

Inland systems

Basin	
OXB	Oxbow
WHO	Waterhole
DEP	Depositional basin
PSD	Prior stream depression
LAV	Lava flow
CRA	Crater
VOL	Other volcanic basins
SOL	Solution
COL	Collapse
TDB	Terminal drainage basin
FAU	Fault
SIN	Sinkhole
MET	Meteor impact
CDU	Coastal interdunal
RDU	Riverine interdunal
ODU	Other interdunal
DEF	Deflation basin
SPR	Spring
GLA	Glacial
IMP	Impoundment
SEW	Sewage ponds
SES	Salt evaporation basin
PIT	Pit (excavation)
Flat	
FLP	Floodplain
Slope	
BAN	Riparian (river bank)
HIL	Hillside
Highland	
MOU	High mountain

Marine systems

Tidal flat	
RRE	Rocky reef
MUD	Mudflat
Estuary	
EST	Estuary

WATER REGIME

Inland systems

PER	Permanent: has water all the time, although the level may vary.
SMP	Semi permanent: has water most of the time but dries out in dry years (eg 1 year in 10).
SEA	Seasonal: floods and dries in most years.
INT	Intermittent: floods irregularly but can be expected to have water at least once per decade and possibly even for several years more or less continuously. This frequency is high enough to influence the type of vegetation present.
EPI	Episodic: only has water at infrequent and irregular intervals (less than 1 year in 10). Such episodic events hardly influence the type of vegetation (except when water is actually present).
DRY	Artificially dry; water source cut off or wetland drained.

Marine systems

ITF	Intertidal flat: inundated by most if not all high tides
STF	Supratidal flat: covered only at spring tides or even less frequently
SFF	Supratidal flat and flooding: relatively rare tidal coverage is combined with seasonal freshwater flooding.

WATER SOURCE

LOC	Local runoff: fed by runoff and infiltration generated by precipitation in the vicinity plus rainfall on the wetland surface; no defined stream
CHA	Channel fed: fed by local runoff entering wetland in artificial channel.
OFF	Off-stream: fed by the river only during floods
STR	Stream-fed: fed by river with a continuous connection
IRR	Irrigation runoff: fed by runoff generated from irrigation; isolated from its natural source. Irrigation runoff will be through a channel so this is a subset of Stream-fed (above).
GRW	Groundwater: fed by groundwater from underground aquifer
SPR	Spring: fed by groundwater coming to surface at a spring beyond the wetland boundary.

MAR	Marine: fed by inflows from the sea, including tides

HABITAT MODIFICATION

0	No effective disturbance; natural
1	No effective disturbance other than grazing by hoofed animals
2	Limited clearing, eg selective logging
3	Extensive clearing, eg poisoning, ringbarking
4	Complete clearing; pasture, native or improved, but never cultivated
5	Complete clearing; pasture, native or improved, cultivated at some stage
6	Cultivation; rainfed
7	Cultivation; irrigated, past or present
8	Highly disturbed, eg quarrying, road works, mining, land fill, urban

WETLAND USE

UND	Unused
CON	Nature conservation
TPR	Timber production
GRA	Grazing
CRO	Cropping
CFI	Commercial fishing
AQU	Aquaculture
RFI	Recreational fishing
DUC	Duck hunting
OHU	Other hunting
WST	Water storage
EXT	Extractive industry
EDU	Education
SCI	Scientific research
MOT	Motor boating
BOA	Boating (non-motor)
SKI	Water skiing
CAM	Camping
BIK	Trail bike riding
HOR	Horse riding
REC	Other recreation

VEGETATION DESCRIPTION

Stratum

H	Highest
M	Middle
L	Lowest
A	Aquatic

GROWTH FORM

for Highest, Middle and Lowest strata (but not predominantly submerged or floating vegetation, see below) (see Appendix 7 for definitions).

T	Tree
M	Tree mallee
S	Shrub
Y	Mallee shrub
Z	Heath shrub
C	Chenopod shrub
H	Hummock grass
G	Tussock grass
D	Sod grass
V	Sedge
R	Rush
F	Forb
E	Fern
0	Moss
N	Lichen
W	Liverwort
L	Vine
X	Xanthorrhoea
P	Palm

for Aquatic stratum (predominantly submerged or floating aquatic vegetation)

S	Submerged
E	Emergent
F	Floating, attached
U	Floating, unattached

	HEIGHT		**COVER**	
		Cover class	**trees and shrubs**	**ground cover**
A	<= 0.25 m		Closed or dense crowns touching to overlapping	70-100%
B	0.26-0.5 m		Mid-dense crowns touching or slightly separated	30-70%
C	0.51–1 m		Sparse crowns clearly separated	10-30%
D	1.01-3m		Very sparse crowns well separated	<10%
E	3.01-6m		Isolated plants	trees 100 m apart; or shrubs 25 m apart
F	6.01-12m		Isolated clumps	clump of 2-5 woody plants, 200 m apart
G	12.01-20m			
H	20.01-35 m			
I	>= 35.01 m			

APPENDIX 2e DEFINITIONS OF CATEGORIES USED IN WETLAND CLASSIFICATION AND SURVEY

CLASSIFICATION ATTRIBUTES

Attributes used to distinguish wetland System, Morphology and Origin are defined and the source of a definition (sometimes modified) or term is given.

System

Inland	wetlands which do not receive any marine waters, even if close to the coast.
Marine	wetlands which are influenced by tidal marine water.

Wetland Morphology

Shallow basin	concave landform (Semeniuk and Semeniuk, in press) generally less than 2 m deep.
Deep basin	concave landform (Semeniuk and Semeniuk, in press) generally greater than 2 m deep.
Flat	flat areas of floodplains (ie not including the river channel) with varying frequency and duration of flooding (Semeniuk and Semeniuk, in press).
Slope	sloping plains with wetland characteristics either due to flooding (eg riverbanks) or the presence of a spring or groundwater seepage (Semeniuk and Semeniuk, in press).
Highland	convex landforms (eg hill tops) which support wetlands in very wet climates (Semeniuk and Semeniuk, in press).
Tidal Flat	intertidal zones of coastal or inlet shorelines exposed to marine tidal water and subject to inundation at least once a year, and not associated with a river mouth (modified from Paijmans *et al.*, 1985). The Mean Low Water Spring tide defines the lower level of the intertidal zone; the Mean High Water Spring tide defines the upper level.
Estuary	intertidal zones of coastal areas associated with open river mouths, influenced by both tidal marine water and river flow. River channels are excluded. The Mean Low Water Spring tide defines the lower level of the intertidal zone; the Mean High Water Spring tide defines the upper level.

Wetland Origin

Deep or shallow basin	
Oxbow	billabong (cut-off anabranch) in floodplain
Waterhole	depressions within river or creek channels which retain water when the channel is otherwise dry
Depositional basin	broad depressions which have formed by deposition in old deflation basins (see below); may be linked or discrete (Pressey, 1986).
Prior stream depression	generally long, sinuous depression marking an old stream bed.
Lava flow	basins formed on the edge of or within lava flows (Paijmans *et aL,* 1985).
Crater	roughly circular basins with deep margins formed in the vent of a volcano (Speight, 1990; Riley *et al.*, 1984).
Other volcanic basins	basins associated with volcanic activity which are neither basins formed by lava flows or craters (Riley *et al.*, 1984).
Solution	depression formed by the solution of limestone (karst landscape) (Riley *et al.*, 1984).

Collapse	depression formed in a karst landscape by collapse caused by solution underground. Unlike Solution depressions, collapse depressions are likely to have blocks of rock in their basins (Riley *et al.,* 1984).
Terminal drainage basin	basin which is the lowest point in an internal drainage basin.
Fault	basin formed from tectonic movement of the earth to block water flow (Riley *et al.*, 1984).
Sinkhole	basin formed from tectonic movement of the earth causing an area to fall relative to its surroundings ('grabben' in Riley *et al.*, 1984).
Meteor impact	crater formed by the impact of an extra terrestrial object.
Coastal interdunal	typically linear or crescent-shaped basins formed between coastal dunes or barrier ridges.
Riverine interdunal	typically crescent-shaped basins formed between riverine dunes (eg 'scroll swales', Pressey, 1986).
Other interdunal	typically linear or crescent-shaped basins formed between dunes not associated with the coast or a river.
Deflation basin	small to very large rounded basins formed by the movement of sediment through wind action. Large deflation basins typically have a crescentic dune (lunette) on their down-wind margin) (Riley *et al.*, 1984; Pressey, 1986).
Spring	basin fed by groundwater discharge (spring)
Glacial	basin scoured out by ice in the late Pleistocene, generally occurring in Tasmania and the Snowy Mountains in NSW (Paijmans *et al.*, 1985)

Basins of human origin

Impoundment	basin formed by damming of a river or creek
Sewage pond	basin constructed as a sewage oxidation basin (Corrick 1980 etc.).
Salt evaporation basin	normally dry basin flooded with saline water as part of saline water removal.
Pit	excavated basin or trench.

Flat

Floodplain	alluvial plain subjected to flooding; usually also containing wetland basins eg oxbow.

Slope

Riparian	slope of river bank.
Hillside	hillside supporting a wetland due to seepage from hill slopes (paluslope in Semeniuk and Semeniuk, in press).

Highland

High mountains	mountain or hill tops subject to seasonal waterlogging in very wet climates (palusmont in Semeniuk and Semeniuk in press).

Vegetation Description Attributes

The vegetation description on the Wetland Field Survey Form is based on that provided in the Australian Soil and Land Survey Field Handbook (McDonald *et al.* 1990). Some modifications were necessary to adequately describe aquatic vegetation. Definitions are given for growth form categories.

Growth Form (from McDonald *et al.* (1990))

Tree	woody plant more than 2 m tall with a single stem of branches well above the base.
Tree mallee	woody perennial plant usually of the genus *Eucalyptus.* Multistemmed with fewer than five trunks of which at least three exceed 100mm in diameter at breast height. Usually 8 m or more tall.

Shrub	woody plant multistemmed at the base (or within 200mm from ground level) or, if single stemmed, less than 2 m tall.
Mallee Shrub	commonly less than 8 m tall, usually with five or more trunks, or which at least three of the largest do not exceed 100 mm in diameter at breast height.
Heath shrub	shrub usually less than 2 m tall, commonly with ericoid leaves (nanophyll or smaller categories, see Field Handbook p.82).
Chenopod shrub	xeromorphic single or multistemmed halophyte exhibiting drought and salt tolerance.
Tussock grass*	forms discrete but open tussocks usually with distinct individual shoots, or if not, then not forming a hummock. These are the common agricultural grasses.
Hummock grass*	coarse xeromorphic grass with a mound-like form often dead in the middle; genera are *Triodia* and *Plectrachne.*
Sod grass*	grass of short to medium height forming compact tussocks in close contact at their base and uniting as a densely interfacing leaf canopy.
Sedge*	herbaceous, usually perennial, erect plant generally with a tufted habit and of the families Cyperaceae and Restionaceae.
Rush	herbaceous, usually perennial, erect plant. Rushes are grouped in the families Juncaceae, Typhaceae, Restionaceae and the genus *Lomandra.*
Forb	herbaceous or slightly woody, annual or sometimes perennial plant; not a grass.
Fern	characterised by land and usually branched leaves (fronds), herbaceous to arborescent and terrestrial to aquatic; spores in sporangia on the leaves.
Moss	small plant usually with a slender leaf-bearing stem with no true vascular tissue.
Lichen	composite plant consisting of a fungus living symbiotically with algae; without true roots, stems or leaves (McDonald *et al.* 1984).
Liverwort	often moss-like in appearance or consisting of a flat, ribbon-like green thallus (McDonald *et al.* 1984).
Vine	climbing, twining, winding or sprawling plant usually with a woody stem.
Xanthorrhoea	grass-trees, genus *Xanthorrhoea*
Palm	palm

* Grasses compared with Sedges (McDonald *et aL,* 1990)

Grasses	**Sedges**
Leaf sheath always split	Leaf sheath never split (except Restionaceae)
Ligule (membranous flap or line of hairs at junction of sheath and blade) present	Usually no ligule
Leaf usually flat	Leaf not always flat
Stem cross-section circular	Stem cross-section circular, triangular or polygonal
Evenly spaced internodes	Extended internode below inflorescence (flower)

3 Landscape assessment

3.1 INTRODUCTION

3.1.1 Aims

The principal aims of this chapter are to:

> present a methodology for determining the visual resource values of wetland landscapes; and
>
> set out guidelines for managing wetlands identified as having high visual resource values within the context of the assessment methodology.

3.1.2 Definition of terms

Landscape Character Types are regions of Victoria delineated on the basis of relative homogeneity of landforms, waterforms and vegetation patterns.

Landscape dimensions are the broad biophysical features that make up any landscape. They include landform, vegetation, waterform, cultural features and fauna.

Landscape Setting Types refer to the land-use patterns surrounding wetlands such as natural, semi-natural, farm forest, agricultural, tourism/recreational, small-town/suburban and urban/industrial areas.

Landscape variables are the detailed elements by which the visual resource value of a landscape is evaluated. These variables include line, form, spatial enclosure, diversity, contrast, legibility, patterns, textures, colour, visibility and accessibility.

Visual resource values of wetlands: are the natural and cultural resources available for human use, enjoyment and perception within or associated with wetland areas.

Wetlands under the Wetlands Conservation Program wetlands are defined as

> areas of marsh, fen, peatland or water, whether natural or artificial, permanent, seasonal or cyclical, with water that is static or flowing, fresh, brackish or salt, including mudflats and mangrove areas exposed at high tide.

Included in the Program are swamps, billabongs and other depressions on floodplains adjacent to streams and all impoundments greater than one hectare. (CFL *et al.* 1988: 3)

Wetland Classification Types reflect the diversity of wetlands in terms of the period of inundation, water characteristics and vegetation species.

3.2 CONTEXT

Wetlands are a feature of Victorian landscapes which have attracted varying degrees of interest and policy attention over the years. It is useful, therefore, to set this chapter in the context of the current state of knowledge about the visual resource values of wetlands.

3.2.1 Traditional views of wetlands

In the past, wetland environments have been little appreciated by the Australian community. This lack of appreciation has centred around a poor understanding of their scientific values (whether ecological, botanical or zoological); and around a common perception that wetlands are both visually unattractive and not conducive to recreational pursuits.

Traditionally wetlands have been perceived as 'swamps'. This pejorative term conjures up images of hostile environments with dirty brackish water, stunted vegetation and mosquitoes. Access to such areas has also generally been viewed as difficult. Recreational opportunities have been identified by only the most hardy recreationists, usually for activities such as fishing and boating.

These traditional attitudes have resulted in a widespread disregard for wetland environments. Consequently approximately one third of Victoria's wetlands has been lost over the last 150 years or so (CFL *et al.* **1988: 1). Drainage, dredging and land-filling, agriculture, mining, water contamination, water supply regulation, salination, erosion, clearing, recreation and fire have all constituted threats to Victoria's wetlands, and still do so.**

3.2.2 Landscape assessment and wetlands conservation in Victoria

The Victorian Government is committed to the conservation and management of wetlands on public land and the protection of wetland habitat on private land. The *Wetlands Conservation Program (WCP)* **(1988), a background document used to guide the management of Victoria's wetlands, recognised the importance of their landscape values:**

> Frequently, wetland vegetation has a rich diversity of colours and textures which, in association with water bodies, often creates a striking visual contrast to the surrounding environment. In this way, wetlands are often of high scenic value and contribute significantly to the quality of the landscape throughout Victoria (CFL *et al.* 1988: 9).

The *WCP* **also outlined the threats to these landscape values:**

> Many land-use practices can have detrimental effects on the landscape values of wetlands, because the patterns and screening capabilities of the vegetation associated with wetlands are so delicate that any change has a disproportionate visual impact. The change in landscape value has significance for the observer within the wetland environment 'looking out' and for the observer on the outside 'looking in'. This means that the visual

> catchment areas of a wetland often extend beyond the immediate wetland environment. Consequently, activities and their management within the visual catchment of a wetland are of crucial importance for wetland management and development (CFL *et al.* 1988: 14).

3.2.3 Changing community perceptions

Growing environmental awareness and concern in the Australian community has led to a change in traditional perceptions. Improved understanding of the scientific and conservation values of wetlands has been accompanied by a greater appreciation of their visual values.

Indeed, visual values are at the frontline of the community's perceptions of wetlands in general. Its visual appearance is the most tangible feature on which members of the general public will base their perceptions of a wetland area's value and management. If the visual resources are being mismanaged—ie if attractive elements of a wetland are being degraded (eg by the removal of significant vegetation) or if negative visual elements (eg powerlines) are introduced into a wetland environment—the visual change will be the impact most obvious to the average observer. Ecological or other scientific changes will be exhibited or manifested in much less visible ways and may only be obvious to individuals with a detailed understanding of ecological or scientific processes, whereas visual changes to the composition of landscape dimensions such as landform, vegetation, hydrological features, fauna and cultural features will be obvious to all observers. These changes are capable of eliciting strong emotive responses amongst observers and generating calls for greater protection.

3.2.4 Accounting for visual values

While concern for the visual resource values of wetlands is evident in some wetlands management plans, these values have not been accorded a central role in decision-making. The hesitancy about including visual resource considerations in determining conservation status has arisen partly because there have not been any recognised means for assessing or quantifying visual values. Professionals concerned with the scientific values of wetlands have generally been concerned that visual values cannot be scientifically or rationally assessed and must rely ultimately on subjective judgements by the assessor of what looks attractive.

It is a fact that little research into this aspect has been carried out in Australia. However, some valuable perceptual preference research studies have been undertaken in the USA. These studies have attempted to assess the visually valuable landscape features of wetlands and to develop a methodology for evaluating or rating them.

Dennis Williamson's work (*Scenic Spectrums* 1986a and 1986b) on scenic assessment for Australia's river landscapes is a valuable reference that suggests one methodology for assessing the visual resource values of riverine environments.

The general findings of these US studies and Williamson's work are set out in Section 3.3. They provide an important conceptual framework on which to base the methodology being developed in this chapter.

3.3 LITERATURE REVIEW

A highly relevant reference for this chapter is a US publication entitled *The Future of Wetlands, Assessing Visual-Cultural Values* (1983) edited by Richard Smardon. It is a compilation of essays exploring approaches to the visual assessment of various types of wetlands ranging from coastal wetlands to river landscapes, estuaries and bogs. Visual perception preference studies were used in many of these approaches to assess the specific visual-cultural resources of wetlands. While the studies themselves are interesting and follow strict methodological guidelines, it is the generalised results of these studies which are of interest in the development of a methodology for the assessment of the visual resource values of Victoria's wetlands. Some of these results are set out below.

State of the Art in Assessing Wetland Visual-Cultural Values (Smardon 1983)

This essay reaches some interesting conclusions regarding visual assessment:

General conclusions

- Smardon's philosophical perspective is that there is a high level of interdependence between visual, recreational and educational values.
- Traditional visual values can be transformed by increased knowledge of ecological functions and context.
- Visual-cultural values vary between regions based on different regional physical attributes.
- Individuals with different cultural values are likely to perceive and value landscapes differently.
- The evaluation of the visual-cultural attributes of wetlands cannot be separated from their landscape contexts.

Specific conclusions

- **The man-made attributes or cultural variables associated with wetlands should be evaluated in relation to their visual use (eg proximity to educational institutions, physical accessibility, and presence of visual intrusions).**
- **Past research has shown that 'tidal marshes, bogs and freshwater marshes rate fairly high in landscape quality in comparison with other landscape types.' (Smardon 1983: 7)**
- **The average user would prefer relatively open wetlands (eg fresh meadows, shallow or deep freshwater marshes, bog mats or low shrub swamps) to thickly vegetated shrub swamps and wooded swamps without visual clearance under the woody canopy. —**
- **There is no correlation between wetland size and level of visual values—ie small wetlands may have high visual resource values.**
- **Spatial enclosure and edge contrast bordering a wetland are important determinants of a wetland's visual values.**

- In general, users prefer a natural (eg forest) or agricultural land use adjacent to wetland areas rather than an urban land-use. Wetlands adjacent to rivers, small lakes, ponds and saltwater bays or inlets are optimum environments from a visual perspective.
- Users like environments that provide mystery and intrigue.
- Textural contrast and patterns formed by open water and aquatic vegetation are striking visual features.
- Constructed elements such as boardwalks may be accepted as compatible with a natural area.
- Dynamic factors such as seasonal changes can have a significant visual impact on visual values.
- Some dynamic influences on wetland visual values (eg tidal flow and wetland wildlife) are the hardest to assess. However, 'wildlife inevitably steals the show from its habitat' (Smardon, 1983: 14).

Wetland Policy and Visual-Cultural Values in the United States, Smardon (1983)

In this article, Smardon states that aesthetic values may include such parameters *as:*

- visual distinctiveness resulting from:
  -prominence;
  -acontrasts due to irregularity in form, line, colour and pattern;
- diversity of elements present including:
  - topographic expression;
  -shoreline complexity;
  - landmarks;
  -vegetation pattern;
  -waterform expression;
  -wildlife visibility.
- compositional harmony or unity of the overall area.

An Evaluation of Wetland Policy in England and Wales (Smardon 1983)

In this article, Penning-Rowsell identifies six character-defining landscape elements:

- landform;
- sky, with variations in light and cloud forms;
- water and associated edge effects;
- vegetation, and its effect on spatial enclosure;
- animals with their environment, numbers and contrast in colour;
- human artefacts eg windmills, towers, chimneys, boats etc.

Assessing Visual Preference for Louisiana River Landscapes (Smardon 1983)

Michael Lee, in this essay, proposes using a theory put forward by Stephen and Rachel Kaplan to devise an evaluative process. Four factors are identified as being important to visual preference in the environment: two informational variables—legibility and spatial definition—and two involvement variables—complexity and mystery:

> *Legibility* involves the clarity or cohesion of a scene, aiding in individual recognition of visual elements. *Spatial definition* primarily involves the arrangement of three-dimensional space within the visual array. It affects orientation and has a definite influence on individual perception and preference.
>
> *Complexity* involves the number and relative distribution of landscape elements. *Mystery* concerns the promise of additional information and encourages an individual to enter a visual display in order to seek this additional yisual data. (Smardon 1983: 47).

Lee devises an evaluative model whereby four main landscape dimensions (vegetation, land, water and total scene) are evaluated against a range of major topics broken down into major variables:

Major Topic	Major Variable
Legibility	Definition Edge contrast
Complexity	Diversity Edge complexity
Spatial definition	Enclosure Depth
Mystery	Mystery
Distinctive elements	Visual distinction Natural shoreline distinction
Disturbance factors	Man-influenced shoreline distinction Visual pollution

The conclusions of Lee's study are that the following landscape variables are highly valued:

- vegetation legibility, ie clear presentation of individual plant forms and internal vegetation structure;
- isual penetration and physical access;
- presence of a strong vegetative edge;
- increased complexity of the water surface;
- complexity/irregularity of the skyline and shoreline (provided legibility is not destroyed);
- significant enclosing or space-defining elements which are important for orientation and the identification of significant scale relationships;
- mystery.

According to Lee, 'For a scene to be of superior visual quality it must maintain a mix or balance of dimensions. One dimension cannot dominate the other dimensions' (Smardon 1983: 55).

Classifying Visual Attributes of Wetlands in the St Lawrence—Eastern Ontario Region (Smardon 1983)

In her article, Molly Burgess Mooney refers to Smardon's identification of the physical dimensions of wetlands important to visual values: water bodies, landform, surrounding land use and wetland vegetation. Mooney reiterates that visual contrast and visual identity of the wetland and its surroundings are the key visual attributes. These attributes are related to each of the resource dimensions as follows:

> *Water-body size* is the existence and quantity of open water that borders, goes through, or is part of a wetland.
>
> *Surrounding land-use contrast* is the difference in edges, or height contrast, of the surrounding land uses.
>
> *Surrounding landform contrast* is the scale of the surrounding landform in relation to the size or scale of the wetland.
>
> *Internal wetland contrast* is the differences in vegetation edges, or height and textural contrast, of the internal edges of the wetlands.
>
> *Wetland-body diversity* is the types of associated water bodies adjacent to or part of a given wetland.
>
> *Surrounding landform diversity* is the variety of landforms surrounding or adjacent to a wetland.
>
> *Surrounding land-use diversity* is the number of different land-use types that border a given wetland.
>
> *Wetland type diversity* is the number of wetland types found within a wetland.
>
> *Wetland-edge complexity* is the complexity of the physical boundary of the wetland where it meets a landform or vegetation edge (Smardon 1983: 100).

Mooney uses these variables to determine Land-Use Types and Landform Types which were synthesised to derive Landscape Units, and to determine Wetland Vegetation Types and Wetland Water-Body Types to derive Wetland Units. Landscape and Wetland Units are then aggregated into character areas. At each stage decision-rules are formulated to facilitate the synthesis. This process provides descriptions and maps of wetland areas but does not provide a basis for evaluating wetland visual-resource values. Such descriptive bases, however, can be used in the planning and design process or used as a data base for evaluation.

A Model for Assessing Visual-Cultural Values of Wetlands: A Massachusetts Case Study (Smardon 1983)

Smardon and Fabos claim that their paper is the first known attempt to develop a fairly rigorous model for assessing visual-cultural values of wetlands. The model attempts to determine the values within a comprehensive system. looking at not only visual values, but natural values as well. In this sense the model does not concur with the aims of this chapter; however, elements of the process described below may be of use.

The Smardon/Fabos model has three different levels:

Level 1—evaluates a given wetland for a possible single outstanding natural, visual landscape or cultural value. If a single outstanding value is not found, the wetland area is assessed at Level 2.

Level 2—evaluates a wetland for several values simultaneously by rating the natural attributes and characteristics of the wetland area. If the combined value of the natural attributes is not substantial, the wetland is evaluated at Level 3.

Level 3—evaluates a wetland's cultural attributes eg accessibility or proximity to urban areas.

At the Level 1 Stage, a single outstanding landscape visual value can be of two kinds:

- A wetland type that is relatively scarce within a specific geographic or physiographic region.
- Visual contrast: 'Visual contrast is provided in the landscape by keeping or introducing landscape types that contrast in height or texture with the general surrounding landscape' (Smardon, 1983: 158).

At the Level 2 stage the principal visual variables employed are:

- landform contrast;
- waterbody size or length;
- surrounding land-use contrast;
- internal wetland contrast;
- landform diversity;
- surrounding land-use diversity;
- wetland edge complexity;
- wetland type diversity;
- associated water-body size;
- diversity of associated water bodies.

Each variable is rated on a scale from 1 to 5, with 5 the highest and 1 the lowest. Each variable is then weighted on the basis of two criteria, immutability and multiple value. 'Immutability is the degree of permanence. The landscape attributes that are more permanent are more valuable for visual-cultural values because they are less likely to be changed naturally or by man's actions' (Smardon, 1983: 162). According to this weighting process, vegetation is rated as highly mutable and landform as immutable. Multiple value compensates for some variables having multiple use values whereas other variables are significant for only one use value.

At the Level 3 stage human-made and cultural attributes, both positive and negative, are acknowledged and weighted. These attributes are defined as:

- educational proximity;

- physical accessibility;
- ambient quality—'the physical condition of the wetland as indicated by the lack of water pollution, air pollution, high noise level, and visible misfits or non-compatible land uses' (Smardon, 1983: 163).

A Review of Previous Studies of the Scenic Assessment of Rivers

(an appendix to *A Preliminary Scenic Assessment Procedure for Australia's River Landscapes* 1986).

In this review, written for the Victoria National Estate Committee, Williamson summarised a number of studies of the 1960s, 1970s and 1980s carried out in Australia and the USA.

Williamson's main conclusions are summarised as follows:

- River scenic quality occurs within a continuum of different landscape types and land use patterns.
- Scenic assessment studies have revealed some important relationships - between landscape features and scenic quality. Williamson's own perception research revealed that increased naturalism has a positive influence on perceived scenic quality and increased landcover diversity has a negative influence on perceived scenic quality.
- Cultural features resulting from human activities can result in river landscapes of extremely high scenic quality.
- Assessment procedures need to consider the most relevant scenic factors while remaining simple and capable of implementation with limited resources.
- There is a large range of characteristics relevant to the scenic assessment of river landscapes (see Appendix 2b).

3.4 ASSESSING VISUAL RESOURCE VALUES OF WETLANDS

3.4.1 General considerations

The assessment procedure must satisfy a number of criteria if it is to be successfully implemented.

The procedure:

- must be simple so that it can be readily understood and implemented by a range of staff with different levels of skills and backgrounds;
- should be capable of being applied generally;
- should be able to be implemented with limited resources and not require extensive or complicated collection activities or high levels of training for assessment personnel;
- should be replicable, ie generate consistent results over many applications irrespective of who performs the test;
- should use the findings of perceptual preference research and environmental psychology for establishing assessment criteria;

- should be applicable on a regional, sub-regional or catchment basis to ensure that as many high value wetlands as possible are protected in each region. If evaluation is only done on a state-wide basis, then the importance of a wetland to its region may be overlooked;
- should provide cues to the formulation of landscape management guidelines;
- would be of added benefit if it provided a priority ranking for 'high value wetlands' and 'other wetlands'.

Three main questions are central to formulating the assessment procedure:

1 What evaluation system is appropriate ?
2 What criteria should be used to measure visual resource value ?
3 How should these criteria be scored and weighted ?

The evaluation system

- Assessments should be made in a frame of reference that clearly identifies the landscape character type, the landscape setting and the type of wetland under consideration.
- A wetland cannot be separated from its surrounding physical landscape. The landscape character types of Victoria (Section 3.4.3) offer a basis for understanding the differences in scenic quality of the landscape surrounding wetlands in different regions of Victoria.
- Adjoining land uses have a significant influence on the visual resource value assessment. Wetland landscape settings should be identified so that wetlands are evaluated or compared within, and not across, different settings (Section 3.4.4).
- The landscape dimensions and variables that imbue a wetland with visual value or meaning will vary between different wetland types (Section 3.4.5). For instance the nature of the attributes of a high value deep freshwater marsh will be different from those of a high value semi-permanent saline wetland;
- Any comparative visual resource evaluations should only be made between wetlands which:
  -have a similar context in terms of the surrounding landscape character type;
  -have a similar landscape setting; and
  -are of the same classification type.

There is little value in trying to compare the visual resource values of a deep freshwater marsh in a coastal landscape character type with a deep freshwater marsh in an eastern highlands landscape character type; or a wetland in a natural landscape setting with one in an agricultural landscape setting. Similarly, it would be inappropriate to compare the visual resource values of a freshwater meadow with those of a silt evaporation basin, irrespective of the surrounding landscape character or landscape setting.

The visual resource values of the immediate wetland landscape will depend on similar landscape dimensions and landscape variables to those of the landscape surrounding the wetland. (The immediate wetland landscape can be defined as an area extending out to a line 0.5 km from the outer edge of the wetland; the surrounding landscape extends outwards from this 0.5 km line.) To simplify the procedure it is recommended that the assessment of visual resource values in the immediate and surrounding landscapes of the wetland be undertaken simultaneously.

- Artificial wetlands and naturally occurring wetlands should be assessed on the same basis.
- High visual resource value will result from a combination of the major landscape dimensions (ie landform, vegetation, waterform, cultural features and fauna) rather than from a single landscape factor. For instance, a scene with high mountains in the background but dead trees and a dry eroded streamcourse in the foreground would not as a whole rate as having a high visual resource value.
- Visual resource value assessments need to take account of negative landscape features as well as positive landscape features. Negative features may be visible either in the immediate vicinity of the wetland or in the surrounding landscape and are most readily assessed simultaneously (see Section 3.4.7).
- There are two polarised views on the relationship between visual values and visual sensitivity. According to one view, visual resource values are not intrinsic values of the landscape. These values only exist in relation to human beings, their perception of the landscape and the meaning they attempt to extract from, or place upon, the landscape. Visual resource values therefore need to take account of the extent to which a particular wetland is viewed by the community. This can be effected by determining an exposure rating which is derived from a combination of two factors: seen area and sensitivity level. According to this view, a wetland landscape which is highly exposed would be assigned a higher visual resource value than an equivalent landscape which is less exposed. This is a measure of visual sensitivity. At the other end of the spectrum lies the opinion that visual resource values are intrinsic features of the landscape; that these values exist irrespective of whether or not they are seen by large numbers of people. Their very existence is enough to warrant their conservation if valued as high. This view also accommodates the notions that individuals gain benefit from merely knowing of their existence and that their potential will be preserved for the enjoyment of future generations.

To ensure that the widest possible net is cast in conserving high value wetlands the second approach is adopted in this chapter. However, visual sensitivity and notions of exposure ratings are considered in Section 3.5 dealing with management guidelines for wetlands.

Criteria used to measure visual resource value

At a more detailed level, the methodology must specify the criteria by which wetland environments are to be assessed for their visual resource value.

The literature reviewed in Section 3.3 provides a guide to the most recent research in the United States and to the application of scenic assessment procedures in Australia. Even relying on this research, complete agreement will never be reached as to what features in the landscape are positive and what are negative in visual terms.

This chapter extrapolates the findings of US perceptual preference research on wetlands to the Victorian situation. Similar approaches have been adopted in the past, and are justified on the basis of the work of Zube and Mills (1976) on cross-cultural studies of landscape perceptions between Australians and Americans. Zube and Mills (1976) concluded that there is considerable agreement among Australians and Americans on scenic evaluation of landscapes. The approach adopted here also relies to a large degree on the expert interpretation of the author and other members of the Capital Development and Management Section of the National Parks Service, Department of Natural Resources and Environment, Victoria, who have extensive experience in looking at these issues.

In terms of assessing the positive visual resource values of wetland environments, the major landscape dimensions regularly mentioned in the research and previous studies are landform, vegetation, waterform, cultural features, and fauna. Cultural features are included in recognition of the fact that human changes to the landscape can add significantly to scenic appeal. In fact, research has indicated that scenes with cultural elements are often preferred to totally natural scenes because they offer a point of orientation, or of the known or familiar. While fauna is often only a ephemeral element in the landscape, perception studies indicate that animals and birds are often considered more important or more attractive elements of a landscape than their habitat.

Within each of these major landscape dimensions there are a number of landscape variables which require consideration. Research indicates that a key variable identified as imbuing landscapes with visual value is diversity. For instance, landscapes with uniform rolling hills, a monoculture of eucalypt woodland and a wetland in the form of a flat-water impoundment would hold little interest for the average observer. Some diversity in these variables (eg mountain peaks in the background, low scrub in the foreground to the woodland, aquatic vegetation in the wetland) together with cultural features and fauna would considerably enhance the visual values of such a scene. The assessment variables listed in Section 3.4.6 have been chosen largely because they contribute visual diversity to the wetland environment. Internal diversity is seen as a positive attribute increasing visual value.

Landscape perception studies have also reached a degree of unanimity on those elements or variables in the landscape that detract from scenic quality. A common feature of these negative variables is that they introduce unacceptable contrast into the landscape in terms of either line, form, colour, pattern or texture. The difference in this contrast (from that considered to be a positive variable) is that it generally results from human alterations. The negative variables are listed in Section 3.4.7.

Scoring the criteria

Assessing visual resource values implies a process of assigning measures of significance to attractive (positive) and unattractive (negative) variables in the landscape. This is inevitably difficult because of the lack of factual, readily measurable variables.

While variables can be proffered on the basis of perception research, the difficulty remains of how to measure them. Valuing normally means assigning either quantitative measures on a scale (5 = high visual resource value, 1 = low visual resource value) or qualitative measures (high, moderate or low visual resource value; extensive, dispersed or nil occurrence); or simply checking the variables for their presence or absence. The latter approach is recommended in this chapter because it is the most objective, relying least on the individual perceptions of assessors.

Another issue often addressed in scoring is the assignment of weights to differentiate important variables from less important ones. For instance, as discussed in Section 3.3, the model put forward by Smardon and Fabos (Smardon 1983) proposes that principal visual variables be weighted on the basis of two criteria: immutability and multiple value. This system proposes that landform variables, which are less mutable, be weighted more highly than vegetation variables, which are more susceptible to change by human activity.

Other procedures contend that certain landscape variables take on greater importance depending on the overall landscape character of the area. For instance, vegetation is seen as a more important determinant of visual value in relatively flat landscape character types.

Others argue that visual resource value must be seen as a combination or harmony of various landscape variables. No one variable should dominate in a particular landscape scene.

In the absence of any research to indicate which variables or combinations of variables, if any, are of greatest significance, this chapter recommends that all landscape variables be treated equally in the assessment process. The determination of high visual resource value based on positive variables is dealt with in Section 3.4.6.

Features which detract from the visual resource value should be assessed for their presence and for the level of their impact on the landscape. Dominant impacts should be distinguished from apparent and inevident impacts. Negative features which can be reduced by management actions should be distinguished from less manageable negative features.

Given that most landscapes are a combination of positive and negative landscape variables, a system must be devised for taking account of both positive and negative values. The recommended approach is set out in Section 3.4.7.

It is recognised that not all field assessors will make consistent evaluations of the landscape variables incorporated in the assessment process. The value of the assessment process must be seen to be in the fact that it provides a rational framework to ensure that a comprehensive range of landscape variables will be taken into consideration with each evaluation.

3.4.2 Basic steps of the methodology

The visual resource value assessment procedure developed below has a number of discrete steps.

These are:

1 to determine the Landscape Character Type (LCT), Wetland Setting Type (WST), and Wetland Classification Type (WCT) for the wetland(s) being assessed;

2 to ensure comparisons only of wetlands which have similar LCTs, WSTs and WCTs;

3 to assess the wetland(s) for the presence of positive landscape variables which are significant;

4 to evaluate whether high visual resource value is achieved on the basis of positive variables;

5 to assess whether any negative features detract from these high visual values; and

6 to arrive at a composite visual resource value (based on positive and negative landscape variables)

Each of these steps is discussed in greater detail and shown graphically in the flowchart opposite.

3.4.3 Landscape character types and assessing visual resource values of the surrounding landscape

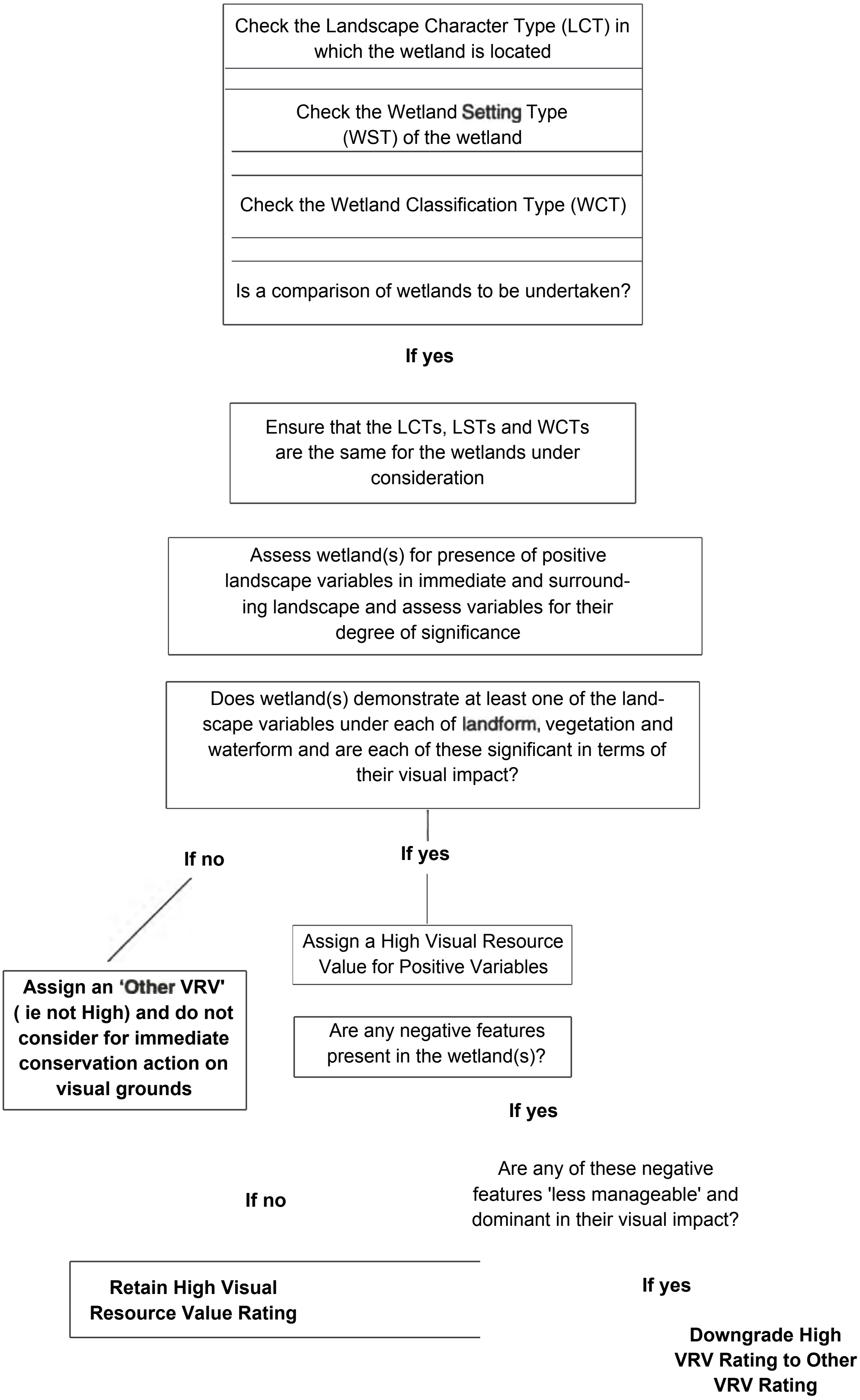
As indicated earlier, the surrounding landscape of a wetland has a large influence on its visual values. To assist in assessing this influence we are able to draw on the *Landscape Character Types of Victoria* (Leonard and Hammond 1984) published by the Forests Commission Victoria as part of its Visual Management System for State Forests. Nine landscape character types are delineated for Victoria based on the relative homogeneity of landforms, waterforms and vegetation patterns.

The nine landscape character types (see Figure 3a) are:

Murray Basin Plains
Western Plains
Southern Lowlands
West Central Hills
Foothills
Eastern Highlands
Grampians
Southern Uplands
Coastline

The Leonard and Hammond study details descriptive criteria for assessing the scenic quality of these landscape character types. The criteria describe the visual features and characteristics, under the headings of Landform, Waterform and Vegetation pattern, which are assessed as representing High, Moderate and Low scenic quality. The high scenic quality classification is assigned where one or more of the categories is assessed as high.

VISUAL RESOURCE VALUE (VRV) METHODOLOGY: FLOW CHART



Check the Landscape Character Type (LCT) in which the wetland is located

Check the Wetland Setting Type (WST) of the wetland

Check the Wetland Classification Type (WCT)

Is a comparison of wetlands to be undertaken?

If yes

Ensure that the LCTs, LSTs and WCTs are the same for the wetlands under consideration

Assess wetland(s) for presence of positive landscape variables in immediate and surrounding landscape and assess variables for their degree of significance

Does wetland(s) demonstrate at least one of the landscape variables under each of landform, vegetation and waterform and are each of these significant in terms of their visual impact?

If no

Assign an 'Other VRV' (ie not High) and do not consider for immediate conservation action on visual grounds

If yes

Assign a High Visual Resource Value for Positive Variables

Are any negative features present in the wetland(s)?

If yes

Are any of these negative features 'less manageable' and dominant in their visual impact?

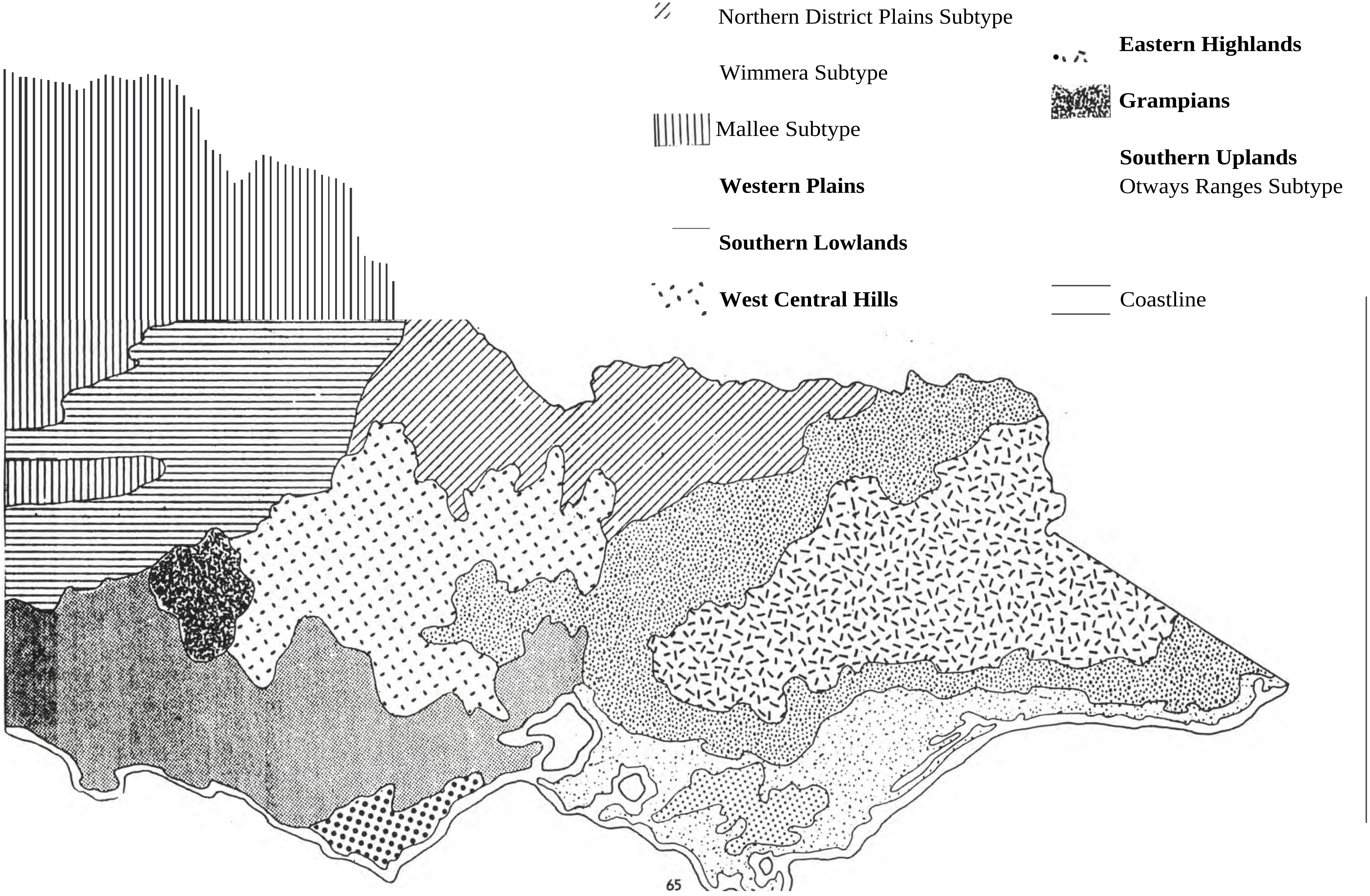
If no

Retain High Visual Resource Value Rating

If yes

Downgrade High VRV Rating to Other VRV Rating

Figure 3a Landscape character types of Victoria



This framework provides a useful means of identifying wetlands that occur within generally similar landscape character types.

Any comparative evaluation of wetlands must be sensitive to the differences in dimensions that imbue a landscape with visual values. Assessments should not attempt to compare the visual values of wetlands in different landscape character types—eg those in a coastal landscape should not be compared with those in the eastern highlands.

While this chapter recommends the use of the Landscape Character Types of Victoria to identify the broad character of the area in which a wetland is located, it does not propose adopting the criteria developed by Leonard and Hammond (1984) to assess the visual values of the surrounding landscape.

Rather, it is *recommended* that the visual values of the surrounding landscape of a wetland be assessed simultaneously with the visual values of the immediate wetland landscape. This assessment process is set out in Section 3.4.6.

This approach has the advantages of:

- reducing the number of checklists to be filled out;
- avoiding the necessity of aggregating separate assessments of the visual values of the immediate and surrounding landscapes;
- ensuring that similar criteria are used in assessing both immediate and surrounding landscapes;
- providing scope for generalising the descriptive assessment criteria compared with those provided by Leonard and Hammond (1984); and
- enabling the use of criteria which will be applicable across all landscape character types.

3.4.4 Wetland setting types

At a more localised level within each of the landscape character types a major factor impinging on visual values is land use. Patterns associated with land use do not generally display the same homogeneity over large areas as the landscape character types. Given the major impact of land-use activities on visual values, it would be illogical to attempt to compare visual values for wetlands in different land-use areas. For the purposes of this study these land-use categories are referred to as 'wetland settings'.

Previous studies have made a similar distinction between landscapes at a local level. *Scenic Spectrums* (1986a) distinguishes between six river setting categories in its scenic rivers assessment procedure: natural, semi-natural, farm forest, agricultural, small-town-suburban and urban-industrial.

Sinden (1990) employs another approach. He distinguishes three settings:

- rivers with eroding banks and minimal vegetation;
- rivers with some improvement works, stable banks and some introduced vegetation;
- rivers with stable banks and native vegetation.

Other procedures have used setting categories such as 'pristine', 'disturbed, but no changes expected', 'agricultural', 'development' (quarries, dams etc), and 'forest'.

The setting categories proposed by Williamson provide the differentiation between land-use activities which is seen as a crucial factor impinging on scenic quality of the landscape adjacent to the wetland. It is *recommended* **that modifications of these categories be adopted for this wetlands chapter. The proposed wetland settings are: 'natural wetland'; 'semi-natural wetland'; 'farm-forest wetland'; 'agricultural wetland'; 'tourism/recreational wetland'; 'small-town/suburban wetland'; and 'urban-industrial wetland' (Appendix 3b).**

3.4.5 Wetland classification types

Just as it is not logical to compare or rate wetlands within different landscape character types or wetland settings, neither is it logical to compare wetland systems of different types for their visual resource value. A classification of wetland types therefore is needed to ensure that such anomalies do not occur.

Wetland classification systems have been devised in the past using a range of significant criteria eg waterbird presence, floristic associations, water regimes etc.

The classification system used in NRE surveys of wetlands and waterbird usage in Victoria (Corrick and Norman, 1980) categorises wetlands on the basis of water depth, duration of inundation and salinity; sub-categories are defined according to the dominant vegetation type.

The main wetland categories in the Corrick and Norman (1980) classification comprise:

Freshwater

- **Flooded river flats**
- **Freshwater meadow**
- **Shallow freshwater marsh**
- **Deep freshwater marsh—permanent**
- **Permanent open freshwater**

Saline

- **Semi-permanent saline**
- **Permanent saline**
- **Sewage oxidation basin**
- **Salt evaporation basin**

Notes on these categories is contained in Appendix 3c.

The Corrick and Norman (1980) wetland classification system is *recommended* **in this landscape study. It has a number of advantages:**

- **This is the system adopted by many other NRE officers working on a range of wetland aspects. Consistency of classification across disciplines should facilitate the integration of the research being undertaken.**

- The basic criteria for classification used by Corrick and Norman have clear visual resource value implications:
  - the duration of inundation. Differentiation on this basis helps account for seasonal factors, which have a large bearing on the water regimes of wetlands and hence on visual values. It would not make sense to compare or rate a wetland which is permanently inundated with a wetland which, because of seasonal factors, may be dry;
  - freshwater versus saline. The saline content of the water has clear implications for the vegetation types associated with a particular wetland and therefore for its visual character. Freshwater wetlands can be characterised by vegetation categories including herbs, sedges, red gums, lignum, cane grass, shrubs, reeds and rushes. Saline wetlands are characterised by different vegetation species—mangroves, glasswort etc.
- By following a system of wetland classification that differentiates wetlands on the basis of some key variables, which have clear visual implications, the visual resource value methodology is assured of addressing the issue of representativeness. By not comparing or ranking wetlands of different types, the methodology ensures that a representative sample of wetland types, with their associated visual values, is conserved.

Landscape dimensions and variables—positive features

As indicated in the literature review (Section 3.3), there are a number of landscape variables which have been shown to contribute positively to high visual value. These variables may be present either in the immediate zone of the wetland or in the surrounding landscape.

A common characteristic of most of the landscape variables is that they impart diversity and/or contrast to the landscape in terms of line, form, colour, texture or pattern. Other important variables include spatial definition or enclosure, legibility, visibility, accessibility, built form and fauna. These criteria are each dealt with below.

Diversity (internal) adds interest and a degree of unpredictability to the landscape. Diversity may be evident in:

- irregularity of line between major dimensions (land and sky; vegetation and sky; water and land; water and vegetation; water and sky; and land and vegetation).
- different landforms, vegetation species, waterbodies and wetland types;
- patterns and textures of vegetation, the water surface, and emergent vegetation in the water.

Contrast can enhance visual values by giving prominence to the main dimensions of the landscape, thereby increasing its legibility. Contrast can exist in:

- the line, form and texture differences between water and landform; separate landforms; water and vegetation; vegetation species; and
- the colours of the sky, water, landform, vegetation, built structures and fauna. Assessments of colour contrasts seek to identify landscapes where the hues of

the landscape are outstanding compared with those commonly observed. The following pairs of colours, taken from the colour wheel in art, give an indication of the types of colour contrasts which generally enhance visual values:

red/green
yellow/purple
orange/blue

Spatial enclosure or definition can add to visual value by imparting a sense of security or protection, or by defining the limits of a landscape to an area which is not too large to take in or comprehend.

Legibility. Humans tend to appreciate landscapes that they can make sense of or understand. Vegetation which is highly contorted, overgrown and haphazard in appearance is less likely to appeal to an observer than vegetation forms which are clearly distinguishable.

Visual penetration/visibility. Wetlands which are readily visible and which allow visual penetration through the vegetation or across the water are likely to have higher visual value than others.

Accessibility. Research indicates that wetlands which offer the prospect of physical accessibility, either in terms of tracks or boardwalks, are visually more attractive to observers. On the other hand, wetlands which are virtually inaccessible can exude an air of hostility which makes them visually less appealing.

Built structures in the landscape can enhance visual values. Enhancing values are often associated with the age of the structure indicating heritage values or with structures which repeat the natural line, forms and colours of the landscape.

Fauna are an ephemeral feature of the landscape, however, research indicates that fauna is visually more appealing than its habitat.

The main positive values identified as contributing to high visual resource value are listed and illustrated graphically in Figure 3b.

Landform

- irregularity of skyline
- spatial enclosure resulting from landform features
- adjacent landform diversity
- internal wetland landform contrast
- strong colour contrasts.

Vegetation

- strong vegetative edge to waterbody
- irregularity of vegetative edges
- legibility of vegetation
- visual penetration through vegetation
- diverse vegetation patterns and textures
- definite water surface patterns and textures created by aquatic vegetation

- spatial enclosure formed by vegetation
- internal wetland vegetation contrast in terms of forms, species and densities
- strong colour contrasts.

Waterform

- irregularity of shorelines
- high visibility of water
- strong spatial definition of waterbody
- strong colour contrasts
- wetland type diversity
- diversity of associated waterbodies.

Cultural features

- good physical accessibility
- interesting built structures and other cultural features (eg boats)
- colour contrasts.

Fauna

- presence and diversity of native fauna
- presence of introduced species related to pastoral activities.

Several of these variables are interrelated and involve more than one of the landscape dimensions identified. For instance, 'water surface patterns and textures created by aquatic vegetation' relates as much to features of the waterform as to features of the vegetation.

Accepting that high visual resource value is a harmony or composition of the above elements with no one element dominating, it remains to be specified what number or combinations of variables must be present for high visual resource value to be attained. There is no simple solution, or mathematical formula, to solve this problem.

Where comparisons of wetlands are not involved (ie where assessments are being undertaken on an ad hoc basis and not comprehensively across a region or catchment), high visual resource value must be established by some rational means. Given that cultural features and fauna are not intrinsic attributes, depending largely on the wetland setting type, high visual resource value should depend primarily on the presence of landform, vegetation and waterform dimensions. It is *recommended* that at least one of the variables under each of the dimensions of landform, vegetation and waterform be present *and* significant in its visual influence for the visual values to be assessed as high.

Where comparisons of wetlands (of the same type, in the same landscape setting and the same landscape character type) are involved, it could be claimed that the wetlands exhibiting the greatest number of these positive variables (including cultural and faunal features) would have the highest visual resource value and vice versa. This is the approach *recommended* in this methodology.

High visual values based on these positive variables may be detracted from by unattractive features in the landscape. It is necessary that these negative features be accounted for in the assessment process. This issue is dealt with in the next Section.

The graphic images on the following pages illustrate the landscape variables listed above. Only those variables that are likely to require explanation for field assessors are included. For instance, no attempt is made to illustrate colour contrasts of landform, vegetation or water body; diversity of wetland type; presence of fauna; or presence of interesting built structures.

3.4.7 Landscape dimensions—negative features

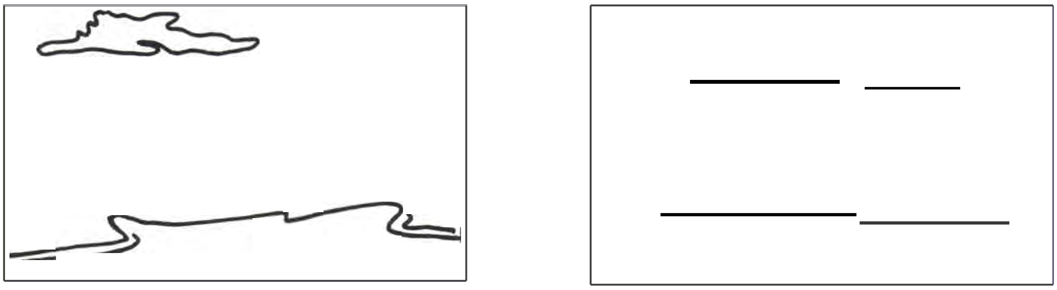
It is possible to identify a range of attributes with the potential to detract from the visual values imparted by positive landscape variables. Such features can detract from positive attributes through misfits of line, colour, form, texture and pattern. In general, detractors are not in harmony with the natural features of the landscape.

Detractors from visual resource value can generally be categorised in two ways: they are either activities or features which can readily or easily be managed through appropriate planning controls; or those which cannot be managed. Negative landscape features are listed below. In the evaluation process it is left to individual officers to make their own judgements of whether these negative features in a particular situation are easily managed or less manageable.

This list has been derived from visual preference studies of what are commonly seen as negative elements in the landscape. There tends to be greater agreement on negative features than on positive visual attributes.

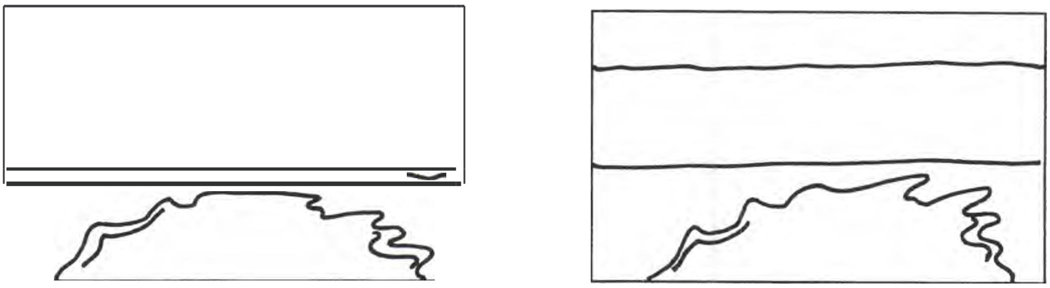
- fences
- signs
- recreation facilities
- storage of materials
- dumped rubbish/pollution
- shoreline disturbance/erosion
- impacts of grazing
- clearings
- unsightly weed invasion
- burning
- management of adjacent private land
- roads and pedestrian corridors
- buildings out of character
- transmission towers, lines and power poles
- pipeline easements
- cuts and fills and quarries
- impoundments (eg weirs)
- drainage/stormwater projects
- water channelling (eg irrigation)
- embankments, berms and levee banks
- water contamination and turbidity
- timber harvests and plantations
- other features.

Figure 3b Sketches illustrating positive landscape variables



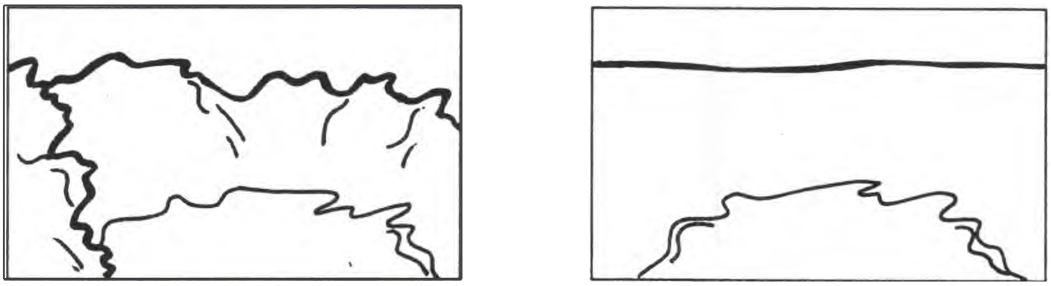
Irregular Skyline

Regular Skyline



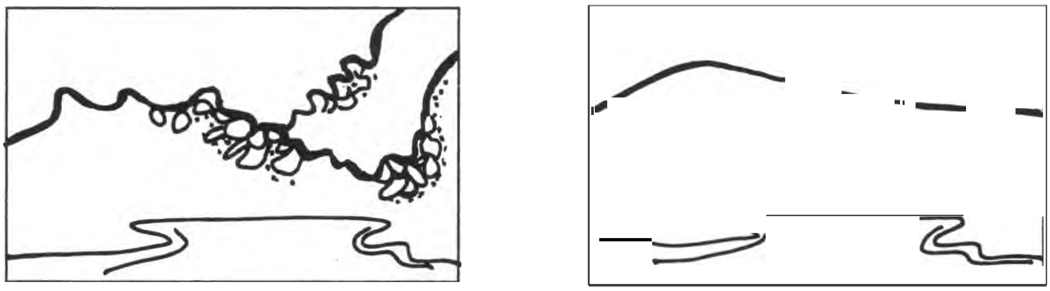
Expansive Skyline

Limited Skyline



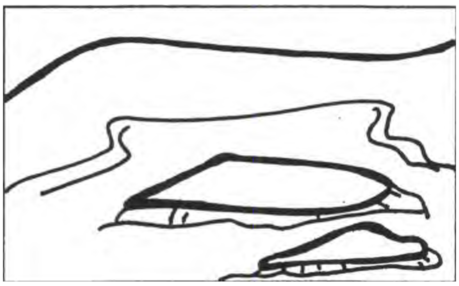
Spatial Enclosure of Landform

Absence of Spatial Enclosure by Landform

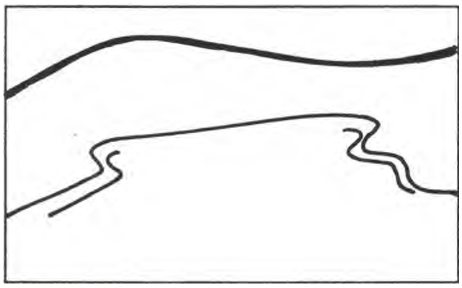


Landform Diversity

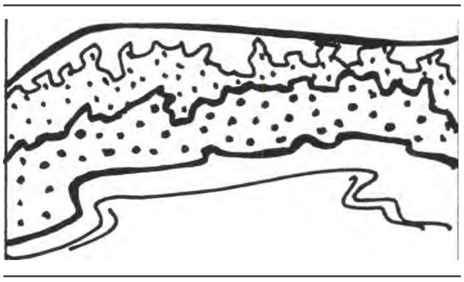
Absence of Landform Diversity



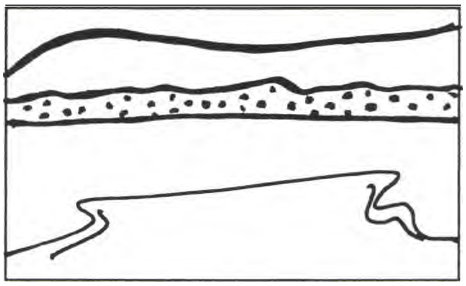
Internal Wetland Landform Contrast



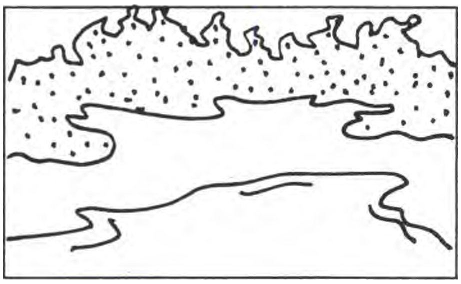
Absence of Internal Wetland Landform Constrast



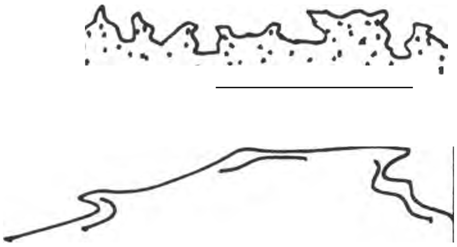
Strong Vegetative Edge to Water Body



Absence of Vegetative Edge to Water Body

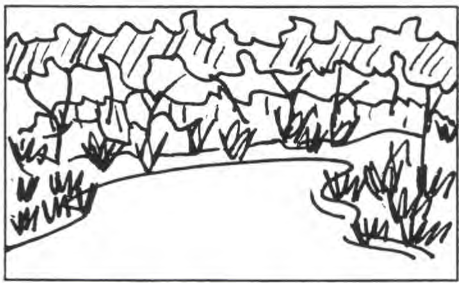


Irregular Vegetative Edge

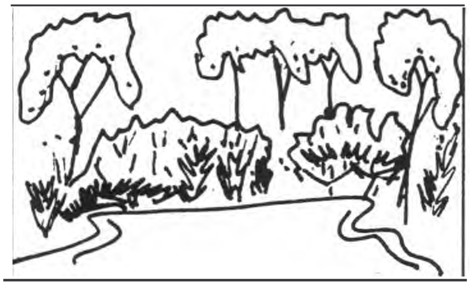


Regular Vegetative Edge

Legible Vegetation, Visual Penetration and Physical Accessibility

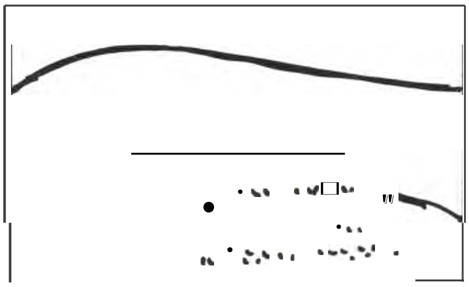


Illegible Vegetation, Visual Obstruction and Physical Inaccessibility

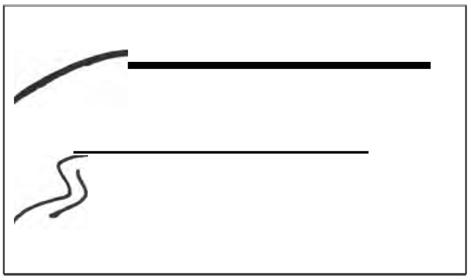


Diverse Vegetation Patterns an Textures

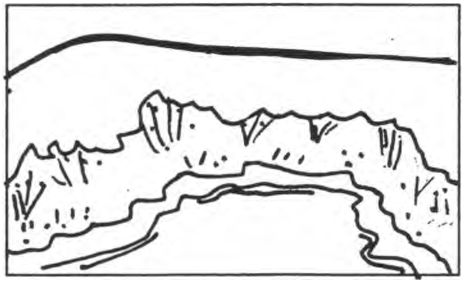
Monotonous Vegetation Patterns and Textures



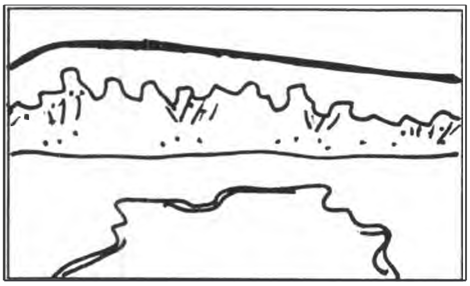
Water Surface Patterns and Textures created by Aquatic Vegetation



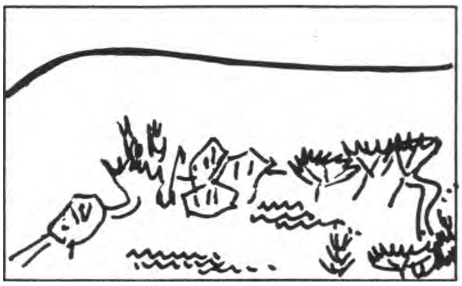
Lack of Water Surface Patterns and Textures



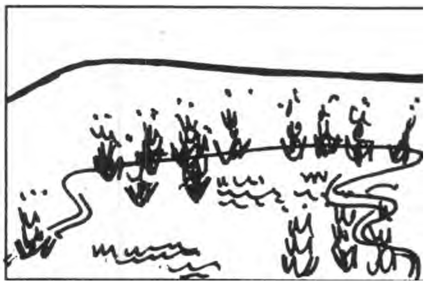
Spatial Enclosure Formed by Vegetation



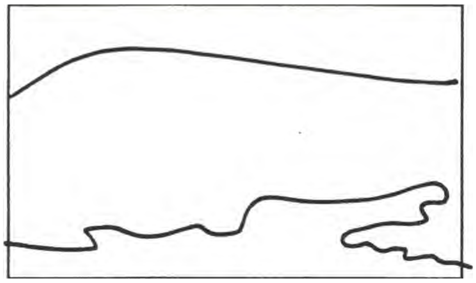
Absence of Spatial Enclosure by Vegetation



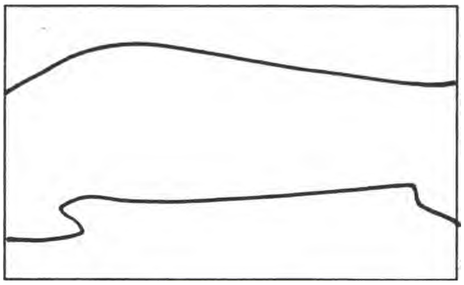
Internal Wetland Vegetation Contrast



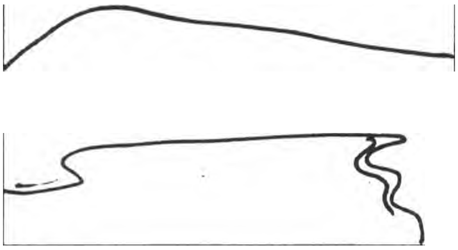
Absence of Internal Wetland Vegetation Contrast



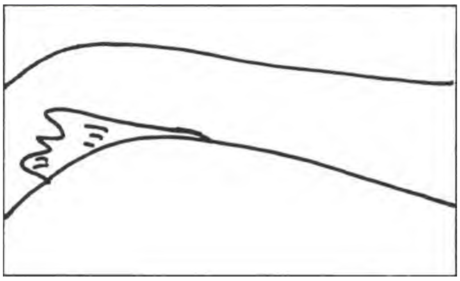
Irregular Shorelines



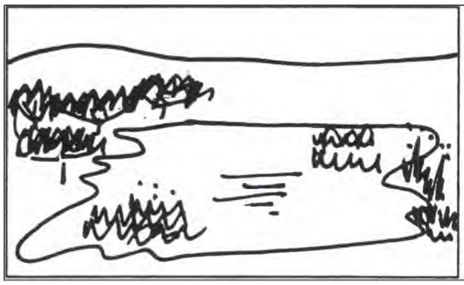
Regular Shorelines



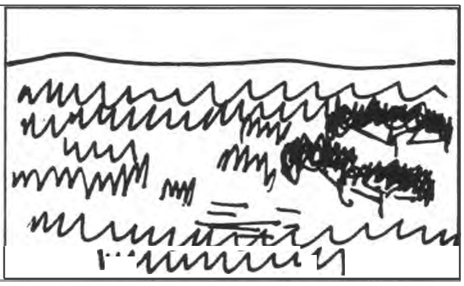
High Visibility of Water Body



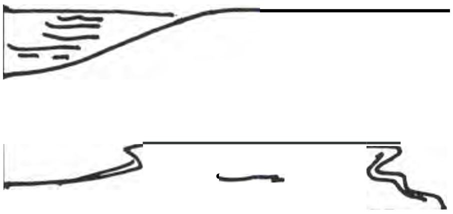
Low Visibility of Water Body



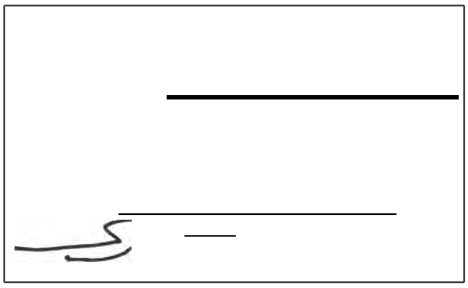
Strong Spatial Definition of Waterbody



Poor Spatial Definition of Waterbody



Diversity of Associated Water Bodies



Absence of Diversity of Associated Water Bodies

Assessors should check the landscapes with high visual resource values based on positive variables for the existence of any of the less manageable detractors and assess whether or not they have a dominant visual impact. Any wetland landscapes where one or more of these less manageable detractors is assessed as being dominant should be down-graded from high visual resource value status. The existence of easily managed detractors should not influence the high value assessments.

The degree of occurrence of easily managed detractors could be used to help rank high visual value wetlands. Where two wetlands are assessed as being of equal visual resource value in terms of the occurrence of positive attributes, the wetland with the lesser number of easily managed detractors should rank higher for conservation purposes.

In assessing negative landscape features it is important to keep in mind the landscape setting type of the wetland under consideration. Features which may detract from a wetland landscape in one setting type may not detract from the landscape in a different type. For instance, while a large corrugated building would detract from a wetland in a semi-natural wetland setting, it could not be considered a negative feature in an industrial wetland setting where such buildings would be considered a normal part of the landscape surrounding the wetland.

Wetland Visual Resource Value Checklist

Location
Wetland Name
Locality
Shire
Region
Map ________AGM ______Lat. Long. - - - - - - -
Landscape Character Type
Landscape Setting Type
Wetland Classification Type
(current Corrick category)
Observation Point
(location from which the wetland is most commonly viewed by the general public.)
Approximate Distance to Wetland
Orientation
Other Relevant Information
Weather Pattern ______________________________
____
____
____
____

Assessment Officer
Name ______________________________
Contact Number ______________________________
Date of Assessment ______________________________

3.4.8 Checklist for assessment process

A checklist for implementing the assessment process is set out above. It is envisaged that officers would take this checklist with them into the field when undertaking a conservation assessment of any wetland. The graphic images contained in Figure 3b under Section 3.4.6 would also be a valuable guide to assessors in the field until they became acquainted with the range of values being assessed.

3.5 MANAGEMENT GUIDELINES

3.5.1 Introduction

The methodology outlined in Section 3.4 was developed to assess the visual resource values of wetlands. The positive attributes contributing to these values are largely natural, although cultural changes to the landscape were acknowledged as potentially important. A range of negative landscape features was also identified as detracting from the visual resource values of a wetland landscape. These negative landscape features were categorised either as easily managed or less manageable and are generally the result of human impacts or alterations to the landscape.

The overall objective of management should be the protection and enhancement of the existing landscape character. Managing the landscape requires the protection and enhancement of positive attributes and, where possible, the amelioration or prevention of any negative impacts.

3.5.2 Easily managed and less manageable landscape changes

The opportunities for managing changes in the landscape vary from one situation to another. Some visual changes are small-scale, relatively temporary and readily amenable to corrective action. For instance burning for weed control, while creating quite a dramatic effect on the visual values of a landscape, has a short-term impact which is reduced with time as natural regeneration occurs. These types of negative landscape features are described as 'easily managed'. As in most processes of change, the degree of reversibility is never complete and some perceptible changes in landscape character are expected to endure. But this is not incompatible with normal processes of change in the environment.

On the other hand, some landscape changes will be large-scale, with dominant visual impacts which are not readily susceptible to ameliorative action. These types of changes are described as 'less manageable'. While management actions to redress the negative visual impacts of these changes may be available, they are unlikely to be sufficient to reverse the negative impact significantly.

Positive landscape variables

	Present (P) or Absent (A)	Significant (S) or Insignificant (I)
Landform		
Irregularity of skyline	☐	☐
Expansive skyline	☐	☐
Spatial enclosure resulting from landform features	☐	☐
Adjacent landform diversity	☐	☐
Internal wetland landform contrast	☐	☐
Strong colour contrasts	☐	☐
Vegetation		
Strong vegetative edge to water body	☐	☐
Irregularity of vegetative edges	☐	☐
Legibility of vegetation	☐	☐
Visual penetration through vegetation	☐	☐
Diverse vegetation patterns and textures	☐	☐
Definite water surface patterns and textures created by vegetation	☐	☐
Spatial enclosure formed by vegetation	☐	☐
Internal wetland vegetation contrast	☐	☐
Strong colour contrasts	☐	☐
Waterform		
Irregularity of shorelines	☐	☐
High visibility of water	☐	☐
Strong spatial definition of water body	☐	☐
Strong colour contrasts	☐	☐
Wetland type diversity	☐	☐
Diversity of associated water bodies	☐	☐
Cultural Features		
Good physical accessibility	☐	☐
Interesting built structures and other cultural features	☐	☐
Strong colour contrasts	☐	☐
Fauna		
Presence and diversity of native fauna	☐	☐
Presence of introduced species	☐	☐

Negative landscape features

	Present (P) or Absent (A)	Dominant (D) or Inevident/ Apparent	Easily managed (E) or Less manageable (L)
Fences	☐	☐	☐
Signs	☐	☐	☐
Recreation facilities out of character	☐	☐	☐
Storage of materials	☐	☐	☐
Dumped rubbish/pollution	☐	☐	☐
Shoreline disturbance/erosion	☐		☐
Impacts of grazing	☐	☐	☐
Clearings	☐	☐	☐
Unsightly weed invasion	☐	☐	☐
Burning	☐	☐	☐
Mismanagement of adjacent private land		☐	☐
Roads and pedestrian corridors		☐	☐
Buildings out of character	☐	☐	☐
Transmission towers, lines and power poles	☐	☐	☐
Pipeline easements	☐		☐
Cuts and fills and quarries	☐	☐	☐
Impoundments (weirs etc)	☐	☐	☐
Drainage/stormwater projects		☐	☐
Water channelling (eg irrigation)	☐	☐	☐
Embankments, berms and levee banks	☐	☐	☐
Water contamination and turbidity	☐	☐	☐
Timber harvests and plantations	☐	☐	☐
Other features	☐	☐	☐

VISUAL RESOURCE VALUE (VRV) ASSESSMENT

A high VRV is attained according to the following rule: where at least one positive landscape variable under each of the landform, vegetation and waterform dimensions is 'present' and 'significant', and where there are no Less Manageable Features with a 'dominant' visual impact.

The following qualification applies: Where one of the three major dimensions (landform, waterform and vegetation) is not visually present, the above rule for assessing VRV should be applied to the other two dimensions only.

	High	Other
Visual Resource Value	☐	☐

3.5.3 General factors influencing visual management

Managing visual resources requires consideration of a number of important factors. This involves assessing both the landscape values and the nature of the development or change proposed. Assessment factors include:

- public sensitivity level of the wetland landscape;
- seen area;
- exposure ratings;
- ability of the landscape to physically absorb change;
- wetland sensitivity type; and
- visual resource value;
- wetland management zones.

3.5.4 Methodology for developing management guidelines

The process of developing management guidelines begins with an assessment of the public sensitivity of the wetland in terms of the types of public use and volumes of use. Combined with an assessment of the wetland's location in relation to the main viewing points (ie whether in the foreground, middleground or background) the public sensitivity levels can be used to derive an exposure rating for the wetland. Wetlands which are observed by high levels of users and which are located in the foreground would be classified as highly exposed. These exposure ratings, together with an assessment of a wetland's ability to physically absorb change (determined largely by slope and vegetation screening characteristics) results in the determination of wetland sensitivity types. A highly exposed wetland with a low ability to physically absorb change would be classified as a high sensitivity type.

A wetland's sensitivity type together with an evaluation of its visual resource value (Section 3.4) facilitates the identification of Wetland Management Zones (WMZs). The zones delineate areas requiring different levels of management if their landscape values are to be protected. High sensitivity type wetlands with high visual resource values would be accorded priority for the application of stringent management guidelines.

The process for determining WMZs for the purposes of establishing management guidelines is shown graphically in the flowchart below.

Public Sensitivity Level of the Wetland Landscape

Inevitable limitations on budgetary and personnel resources require that priorities be set in managing change in the landscape. An important consideration in setting such priorities is the public sensitivity of the wetland landscape being assessed. According to Williamson and Calder (1979:332), public sensitivity levels relate to different degrees of public concern for scenery. From a management point of view, wetlands which have high visual resource values and a high level of public sensitivity have a higher priority for visual management than wetlands with similar visual values but low public sensitivity.

According to the system which was developed by the Forests Commission Victoria for the visual resource management of Victoria's forests, it is possible to classify travel routes and use areas into levels of public sensitivity (level 1—high, level 2—moderate and level 3—low) based on public perceptions of landscape, observer types and observer volumes. While this system was developed following research which was directed specifically towards management of visual resources in forests, it is proposed that an adapted version, as shown below, be employed in managing wetland landscapes.

This assessment of public sensitivity to the visual resource values of wetlands is an important step in developing wetland management zones.

Level 1: High Sensitivity
- Freeways and state highways with more than 500 vehicles/day
- Classified tourist roads
- Main sealed roads with more than 75 vehicles/day
- Recreation, cultural or scenic sites and viewpoints of national or interstate significance
- Walking tracks of national significance
- Residential areas with high degrees of scenic concern
- Interstate passenger rail lines with daily services
- Rail lines of cultural, historic or scenic significance
- Navigable rivers, lakes and reservoirs of national recreation significance.

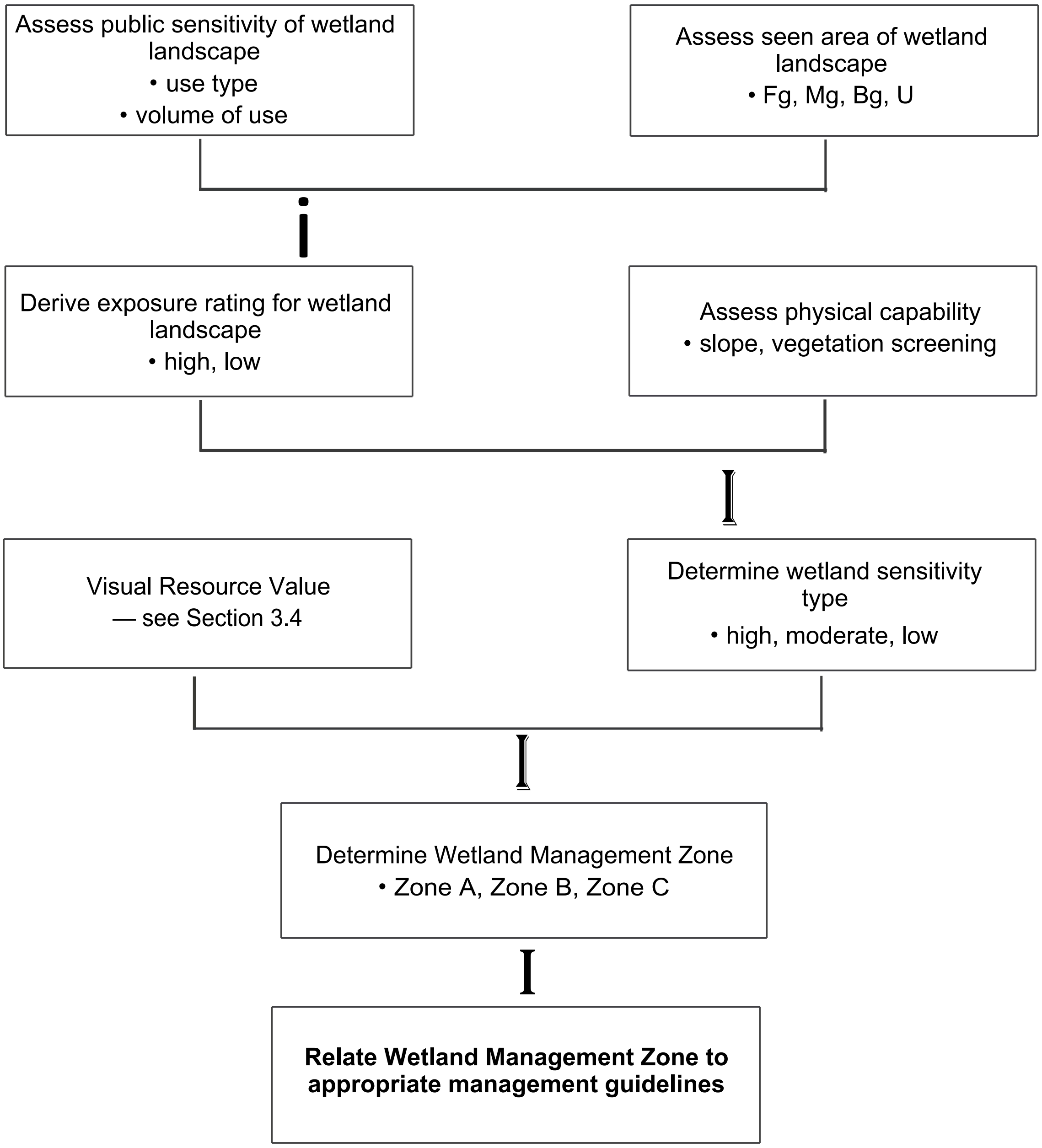
Level 2: Moderate Sensitivity
- Main sealed roads with more than 50 vehicles/day
- Other roads with more than 35 vehicles/day
- Roads with less than 35 vehicles/day, but planned for recreation use within five years
- Recreation, cultural or scenic sites of state significance
- Tracks of state or high local significance
- Residential areas with moderate degrees of scenic concern
- State passenger rail lines with daily rural town services
- Navigable rivers, lakes and reservoirs of state recreation significance

Level 3: Low Sensitivity
- Roads with occasional recreation traffic up to 10 vehicles/day
- Walking tracks of low local significance
- State passenger rail lines with less than daily rural town services

Seen area

The management actions appropriate to a particular wetland landscape will also depend on the viewing characteristics of the wetland and of any proposed changes. For example, wetlands which are located in the foreground of a major travel route or a user area (such as key observation points) will require more intense or sensitive management because of their greater visibility than wetlands located in the middleground or background.

MANAGEMENT GUIDELINES: FLOWCHART



Managers therefore need to make an assessment or inventory of the 'seen area' from the key viewing points. The seen area is the landscape that can be seen from these viewing points. It is also known as the viewshed. Where a landscape is seen from several points, eg along a road, the seen area should account for all the visible landscape along the route.

For management purposes Williamson and Calder (1979: 334) divide seen area into three viewing distance zones measured from the observation point: foreground, middleground and background:

> Foreground is the area between the observation point and approximately 0.5 km away, where textural details of the landscape are visible. Middleground is the area approximately 0.5 to 6.5 km away, where textural patterns are visible, but landscape details are not discernible. Background is the area approximately 6.5 km to 16 km away in which landscape textures are no longer visible and impressions are dominated by forms and colours in the landscape.

Exposure ratings

The concepts of public sensitivity and seen area can readily be combined to derive an exposure rating for a particular wetland landscape being assessed. The proposed exposure ratings representing a combination of these two factors are shown in Table 3a below:

Table 3a **Exposure ratings**

		Seen area			
		Foreground	Middleground	Background	Unseen
Sensitivity Level	Level 1	High	High	High	Low
	Level 2	High	High	Low	Low
	Level 3	High	Low	Low	Low

Physical Absorption Capability (PAC)

Apart from taking into account how wetland landscapes are perceived and their visibility, planning for change needs to consider the physical characteristics of the landscape. Some landscapes are physically better able to absorb change than others.

Previous studies have identified a range of characteristics which influence the physical absorption capability of a landscape. These include slope, erosion potential, and vegetation screening. Field observations have indicated that slope and vegetation screening are the primary determinants.

Drawing on the Forests Commission Victoria (1981: 20)

> Slope is the relative terrain steepness measured as a ratio of vertical elevation to horizontal distance, expressed in percentage, or measured as a geometric angle, expressed in degrees.

The visual implications of slope characteristics are as follows:

> As the slope of the terrain becomes increasingly steep, a greater area of land surface becomes more directly visible and the screening potential of intervening vegetation decreases.

Vegetation screening classes are also defined by the Forests Commission Victoria (1981: 26):

> Vegetation Screening is the relative potential of trees, shrubs, and grasses to filter or obscure views to other landscape features or alterations. Vegetation screening is measured as a function of the height and density of trees, shrubs and grasses.

The visual implications of vegetation screening classes are as follows:

> Vegetation varies in its ability to screen views of landscape alterations. For any given slope, tall dense vegetation will provide a relatively effective screen, while short sparse vegetation provides a relatively ineffective screen.

Combining these slope and vegetation screening characteristics it is possible to derive a measure of a wetland's physical absorption capability (Table 3b).

The physical absorption capability is high for areas with high-dense vegetation screening and slopes less than 30%. High-dense vegetation on steeper slopes reduces the PAC to moderate. Moderate vegetation screening on slopes of less than 30% also gives a moderate PAC. Low PAC is typical of all areas with low-sparse vegetation, irrespective of slope, and where moderate vegetation screening is found on slopes in excess of 30%.

Table 3b Physical Absorption Capability

		Vegetation screening		
		High-Dense	Moderate	Sparse
Slope	0-5%	**High**	**Moderate**	Low
	6-29%	**High**	Moderate	Low
	30+%	Moderate	Low	Low

Wetland sensitivity types

Exposure ratings (public sensitivity level plus seen area) in combination with physical absorption capability (PAC) can be combined to determine the sensitivity level of a wetland.

Table 3c shows a matrix of exposure ratings in the columns and PACs in the rows. Highly exposed wetland landscapes with a low ability to physically absorb change are rated as the most sensitive wetland types. Sensitivity levels decrease from high for this scenario to very low for wetland landscapes with low exposure and high ability to visually absorb change.

Table 3c Wetland sensitivity types

		Exposure ratings	
Physical absorption capability	High	Moderate	Very Low
	Moderate	Moderate	Low
	Low		Moderate

Wetland management zones

Wetland management zones are based on the combinations of specific visual resource value classes and wetland sensitivity types as determined by physical absorption capabilities and exposure ratings. High visual resource value was defined in Section 3.4 as a combination of certain landform, vegetation and waterform characteristics relating to such factors as diversity, contrast and legibility. Three WMZs are identified in Table 3d Zone A; Zone B; and Zone C. These zones relate only to wetlands with high visual resource value.

This process establishes priorities for managing wetland landscapes. The highest priority for management (ie Zone A) is accorded to wetland landscapes with high visual resource value and high overall sensitivity. Middle level management priority (ie Zone B) is accorded to wetland landscapes with high visual resource value and moderate overall sensitivity. The lowest management priority (ie Zone C) is assigned to wetland landscapes with high visual resource value and low to very low overall sensitivity.

Table 3d Wetland management zones

		Wetland sensitivity type			
		High	Moderate	Low	Very Low
Visual Resource Value	High	Zone A	Zone **B**	Zone **C**	Zone **C**
	Other	*	*	*	*

*** Not relevant to this chapter**

Each wetland management zone has associated visual quality objectives that recommend the degree of visual alteration desired for that Zone.

The visual quality objectives of the three zones are:

Zone A: landscape changes should have a low or inevident impact;

Zone B: landscape changes should have an apparent but not dominant visual impact;

Zone C: landscape changes can be visually dominant but should harmonise with the existing landscape.

3.5.5 Management guidelines

Given the identification of Wetland Management Zones and associated visual quality objectives, a range of management guidelines for each of the negative visual features identified in Section 3.4.7 have been formulated. The positive features identified as contributing to high visual resource values of wetlands are largely natural attributes many of which cannot be readily managed. The landform and waterform features in particular are large-scale dimensions which would only be altered if subject to major earthworks operations. Clearing and replanting are the main threat to the positive vegetation features. Buildings and the provision of access are cultural features which could lower visual values. Fauna is a positive feature which requires careful ecological management beyond the scope of these guidelines. Essentially, the positive features should be maintained or left =disturbed. The management of threats to these features is dealt with under the following guidelines.

In reality, all landscapes subject to human intervention need to be managed. If wetlands with low visual values are not managed their scenic resource will be further degraded and may reach a point where the adverse impacts are irreversible. Moreover, good design is not a practice to be used only when dealing with high visual resource value wetlands; it should be employed in all situations where landscape changes are contemplated.

Despite these qualifications, the management guidelines listed below have been drawn up with a view to protecting wetlands assessed as having high visual resource values. They are a basic guide to what level of change is acceptable for a particular wetland landscape. Alternative guidelines are proffered for each of the wetland management zones (A, B and C). The most stringent controls apply to Zone A wetland management zones. The controls apply to any changes within the viewshed of the wetland.

Fences

Zone A		Zone C
• Use natural landscape features or plantings to form required barriers and visual screens	Limit the extent of fencing, using natural landscape features as barriers where possible	Allow fencing subject to careful siting and design
• Barriers and screens should follow the contour of the land	Fencing should follow the contours of the land and avoid ridge tops	Fencing should follow the contours of the land and avoid ridge tops
• Fencing should not be visible from key viewing points	Assess the visual impact of proposed fencing as seen from key viewing points	Fencing should not diminish the screening potential of existing vegetation and landform
• Fencing materials and colours should harmonise with the surrounding landscape	Fencing materials and colour should harmonise with the surrounding landscape	Fencing materials and colours should harmonise with the surrounding landscape
• Use wire mesh fencing for temporary uses eg plant establishment	Where possible, use wire mesh fencing for temporary uses eg plant establishment	Where possible, use wire mesh fencing for temporary uses eg plant establishment

Signs

Zone A	Zone B	Zone C
• Explore alternatives to signs such as brochures and maps	• Limit the number of signs to those strictly required for directional and interpretive purposes	• Limit the number of signs to those strictly required for directional and interpretive purposes
• Avoid siting any signs in locations visible from key viewing points	• Minimise the visual impact of signs visible from key viewing points	• Minimise the visual impact of signs visible from key viewing points
• Use standard NRE signs for directional, name and interpretive signs	• Use standard NRE signs for directional, name and interpretive signs	• Use standard NRE signs for directional, name and interpretive signs
• Use sign colours that harmonise with the surrounding landscape	• Use sign colours that harmonise with the surrounding landscape	• Use sign colours that harmonise with the surrounding landscape
• Relate the size of the sign to the scale of the surrounding landscape	• Relate the size of the sign to the scale of the surrounding landscape	• Relate the size of the sign to the scale of the surrounding landscape

Recreational use / facilities

Zone A	Zone B	Zone C
• Prohibit recreational activities on or adjacent to wetlands where there is a potential to degrade visual resources • Prohibit the construction of recreational facilities adjacent to wetlands • Recreational facilities and activities should not be visible from key viewing points	• Assess the level of impact on visual resources of each proposed recreational activity • Assess the visual impact of proposed recreational facilities • Assess the visual impact of proposed recreational facilities and activities as seen from key viewing points	• Permit recreational activity unless it can be demonstrated that it degrades the visual resource • Allow the construction of recreational facilities subject to careful design • Recreational facilities and activities should not diminish the screening potential of existing vegetation and landform

Storage of materials

Zone A	Zone B	Zone C
• Avoid storage of any materials adjacent to wetlands or on private land adjoining wetlands	• Assess the visual impact, particularly from key viewing points, before storing any materials adjacent to wetlands or on private land adjoining wetlands	• Allow storage of materials adjacent to wetlands or on land adjoining wetlands provided it is screened by vegetative buffers

Dumped rubbish pollution

Zone A	Zone B	Zone C
• Prohibit the dumping of rubbish or other polluting activities in wetland waters or on adjacent land • Rubbish bins should be designed to be unobtrusive in colour and form • Rubbish bins should be located away from wetlands • Visitors should be encouraged to remove their own rubbish	• Prohibit the dumping of rubbish or other polluting activities in wetland waters or on adjacent land • Rubbish bins should be designed to be unobtrusive in colour and form • Rubbish bins should be located away from wetlands • Visitors should be encouraged to remove their own rubbish	• Prohibit the dumping of rubbish or other polluting activities in wetland waters or on adjacent land • Rubbish bins should be designed to be unobtrusive in colour and form • Rubbish bins should be sensitively sited

Shoreline disturbance, erosion and earthworks

Zone A	Zone B	Zone C
• Earthworks should be avoided	• All earthworks should be restored with appropriate planting	• Earthworks assessed as having a significant visual impact should be restored with appropriate planting
• Eroded areas should be rehabilitated using appropriate techniques (including indigenous plantings) as soon as possible	• Eroded areas should be rehabilitated using appropriate techniques (including indigenous plantings)	• Eroded areas should be rehabilitated if unstable
• Areas of high erosion potential should be excluded from any development works	• Areas of high erosion potential should be excluded from any development works	• Development in areas of high erosion potential should be carefully designed and landscaping carried out

Impacts of grazing

Zone A	Zone B	Zone C
• Avoid vegetation destruction and erosion by prohibiting grazing	• Limit vegetation destruction and erosion by restricting stock access	• Allow grazing in accord with physical carrying capacity of the land
• Maintain access by grazing native animals such as kangaroos	• Maintain access by grazing native animals such as kangaroos	• Maintain access by grazing native animals such as kangaroos

Clearings / revegetation works

Zone A	Zone B	Zone C
• Avoid the clearing of indigenous vegetation for road construction, buildings, recreation facilities etc	• Minimise vegetation clearing for road construction, buildings, recreation facilities and allow for revegetation works	• Minimise vegetation clearing
• Revegetate with indigenous species from trees down to aquatic species in natural settings	• Revegetate with indigenous species from trees down to aquatic species in natural settings	• Revegetate with indigenous species from trees down to aquatic species in natural settings
• In cultural landscapes revegetate with appropriate introduced, native and indigenous species	• In cultural landscapes revegetate with appropriate introduced, native and indigenous species	• In cultural landscapes revegetate with appropriate introduced, native and indigenous species
• A landscape plan should be developed for all revegetation works	• A landscape plan should be developed for all revegetation works	• A landscape plan should be developed for all revegetation works

Weed invasion

Zone A	Zone B	Zone C
• Remove weeds which have an apparent visual impact on the landscape • Use weed eradication measures which have only a short-term visual impact on the landscape	• Remove weeds which have an apparent visual impact on the landscape • Use weed eradication measures which have only a short-term visual impact on the landscape	• Remove weeds which have a dominant visual impact on the landscape • Use weed eradication measures which do not have a long-term visual impact on the landscape

Burnin

Zone A	Zone B	Zone C
• Ensure that any fire protection works and prescribed burning have only a short-term and localised visual impact on the landscape	• Ensure that any fire protection works and prescribed burning have only a short-term and localised visual impact on the landscape	• Ensure that any fire protection works and prescribed burning do not have a long-term visual impact on the landscape

Private land -use adjacent

Zone A	Zone B	Zone C
• Allow developments which are in harmony with the natural landscape setting	• Proposed developments should borrow, where possible, from the features of the surrounding landscape	• Proposed developments should borrow, where possible, from the features of the surrounding landscape
• Discourage proposed developments which are out of character with the natural landscape setting	• Proposed developments out of character with the landscape character should be carefully sited and screened	• Proposed developments out of character with the landscape character should be carefully sited and screened
• New developments should not be visible from key viewing points	• Assess the visual impact of proposed new developments visible from key viewing points	• Allow new developments (in character with the natural setting) where visible from key viewing points
• Ensure that new developments on adjacent land accord with other relevant guidelines eg earthworks, clearings/revegetation, fences, buildings etc	• Ensure that proposed new developments on adjacent land accord with other relevant guidelines eg earthworks, clearings/revegetation, fences, buildings etc	• Ensure that proposed new developments on adjacent land accord with other relevant guidelines eg earthworks, clearings/revegetation fences, buildings etc

Pedestrian access

Zone A	Zone B	Zone C
• Restrict pedestrian access to clearly defined pathways to prevent destruction of vegetation	• Restrict pedestrian access to clearly defined pathways to prevent destruction of vegetation	• Allow more informal pedestrian access where this does not degrade the landscape
• Pathways should follow contours of the land	• Pathways should follow contours of the land	• Pathways should follow contours of the land where possible
• Pedestrian bridges should not be sited over wetlands	• Pedestrian bridges should not be sited over wetlands	• Assess the visual • impact of proposed pedestrian bridges over wetlands
• Pathway materials should be sympathetic to the existing landscape character	• Pathway materials should be sympathetic to the existing landscape character	• Pathway materials should be sympathetic to the existing landscape character
• Pathways should accord with strictest construction standards eg width	• Pathways should accord with strictest construction standards eg width	. Pathway construction to meet normal construction standards
• Design pathway to limit disturbance to fauna	• Design pathway to limit disturbance to fauna	• Design pathway to limit disturbance to fauna

Buildings

Zone A	Zone B	Zone C
• Avoid siting non-wetland-related buildings (eg information centres, management offices) adjacent to wetlands	• Avoid siting non-wetland-related buildings (eg information centres, management offices) adjacent to wetlands	• Avoid siting non-wetland-related buildings (eg info centres, management offices) adjacent to wetlands
• Limit the height of buildings to one storey	• Limit the height of buildings to one storey where possible and assess the visual impact of any taller buildings	• Assess the visual impact of proposed buildings taller than one storey
• Use structural forms which borrow from the forms of the landscape	• Use structural forms which borrow from the forms of the landscape	• Use structural forms which borrow from the forms of the landscape
• Use building materials, finishes and colours which harmonise with the surrounding landscape	• Use building materials, finishes and colours which harmonise with the surrounding landscape	• Use building materials, finishes and colours which harmonise with the surrounding landscape
• Buildings should be of the highest quality in design and construction	• Buildings should be of high quality in design and construction	• Buildings should be of high quality in design and construction
• Portable and temporary buildings and structures should not be allowed	• Assess the visual impact of proposed temporary buildings and structures	• Portable and temporary buildings and structures should be carefully sited and designed
• Buildings should not be visible from key viewing points	• Assess the visual impact of proposed buildings as seen from key viewing points	• Buildings should not diminish the screening potential of existing vegetation and landform

Vehicle mana ement

Zone A	Zone B	Zone C
• Do not build roads adjacent to wetlands	• Assess visual impact before constructing roads adjacent to wetlands	• Allow roads adjacent to wetlands provided adequate buffers of vegetation or landform are present
• Access roads into a wetland area should follow contours of land and terminate well short (0.5 km) of wetland	• Access roads into a wetland area should follow contours of land and facilitate easy pedestrian access to wetland	• Access roads could afford point access to wetland if carefully designed
• Access roads should not be visible from key viewing points	• Assess the visual impact of proposed access roads as seen from key viewing points	• Access roads should not diminish the screening potential of existing vegetation and landform
• Carparks should be located away from wetlands	• Assess the visual impact of proposed carparks sited near wetlands	• Carparks could afford easy access to wetlands if carefully designed
• Carparks should not be visible from key viewing points	• Assess the visual impact of proposed carparks as seen from key viewing points	• Carpark development should not diminish the screening potential of existing vegetation and landform
• Vehicular bridges should not be sited over or adjacent to wetlands	• Vehicular bridges should not be sited over wetlands and the visual impact of proposed adjacent bridges should be assessed	• Assess the visual impact of proposed vehicular bridges over or adjacent to wetlands
• Road and carpark materials should be sympathetic to the existing landscape character	• Road and carpark materials should be sympathetic to the existing landscape character	• Road and carpark materials should be sympathetic to the existing landscape character
• Major earthworks should be avoided	• Major earthworks should be avoided or restored as soon as possible	• Earthworks assessed as having a significant visual impact should be restored
• Road construction should avoid the clearing of indigenous vegetation	• Road construction should minimise vegetation clearing and allow for revegetation works	• Road construction should minimise vegetation clearing
• Roadside vegetation should be maintained or enhanced	• Roadside vegetation should be maintained or enhanced	• Roadside vegetation should be maintained

Structures

Zone A	Zone B	Zone C
• Assess the visual impact of any wetland-related structures, eg piers, deemed to be essential	• Limit the number of wetland-related structures to those strictly required	• Allow desired wetland-related structures subject to design constraints
• Bird hides should blend with the surrounding landscape in terms of line, form and colours	• Bird hides should blend with the surrounding landscape in terms of line, form and colours	• Bird hides should blend, as much as possible, with the surrounding landscape in terms of line, form and colours
• Bird hide construction should minimise disturbance in terms of cuts and fills, vegetation clearing, shoreline stability	• Bird hide construction should minimise disturbance in terms of cuts and fills, vegetation clearing, shoreline stability	• Bird hide construction should minimise disturbance in terms of cuts and fills, vegetation clearing, shoreline stability
• Nesting boxes should be located outside the key viewing points	• Nesting boxes should, where possible, be located outside the key viewing points	Nesting boxes should be sensitively sited
• Nesting boxes should preferably be made of timber allowed to weather over time	• Nesting boxes should preferably be made of timber allowed to weather over time	Nesting boxes should be made of timber or other materials with a minimal visual impact
• The scale and form of nesting boxes should complement the wetland setting	• The scale and form of nesting boxes should complement the wetland setting	• The scale and form of nesting boxes should complement the wetland setting as much as possible

Services (transmission lines, pipelines etc)

Zone A	Zone B	Zone C
• Avoid overhead transmission towers/lines/poles, underground lines, pipelines etc requiring cleared corridors	• Assess the visual impact of proposed overhead transmission towers/lines/poles, underground lines, pipelines etc requiring cleared corridors	• Assess the visual impact of proposed overhead transmission towers/lines/poles, underground lines, pipelines etc requiring cleared corridors
• No vegetation clearing of corridors to accommodate any services	• Assess the visual impact of any proposed vegetation clearing of corridors to accommodate services	Minimise vegetation clearing to accommodate services and use irregular clearing edges
	• Maintenance of any corridors should avoid broadscale poisoning of vegetation and uniform clearing	Maintenance of any corridors should avoid broadscale poisoning of vegetation and uniform clearing
	• Any towers, poles etc should be painted to harmonise with the surrounding landscape	Any towers, poles etc should be painted to harmonise with the surrounding landscape
	• Junctions of any services with major travel routes should be at right angles	Junctions of any services with major travel routes should be at right angles

Cuts fills and quarries

Zone A	Zone B	Zone C
• Earth cuts and fills should be avoided wherever possible	• The visual impact of proposed cuts and fills should be assessed and only minimal excavation and fill allowed	• Earth cuts and fills should be minimised and rehabilitated wherever possible
• Quarrying activity should be avoided	- The visual impact of proposed quarrying activity should be assessed. Permitted activity should be strictly controlled	• The visual impact of proposed quarrying activity should be assessed

Impoundments

Zone A	Zone B	Zone C
• The visual impact of proposed impoundment structures to be assessed. Inevident structures only permitted	• The visual impact of proposed impoundment structures to be assessed. Minimal visual intrusion only permitted	• Impoundment structures to have low visual impact

Drainage / stormwater / irrigation / channelisation

Zone A	Zone B	Zone C
• Avoid stormwater, irrigation and channelisation works which would have a visual impact on the landscape	• Assess the visual impact of stormwater, irrigation and channelisation works and minimise the impact through careful siting and design	• Minimise the visual impact of stormwater, irrigation and channelisation works through careful siting and design
• Use vegetated berms and levees as visual buffers	Use vegetated berms and levees as visual buffers	• Use vegetated berms and levees as visual buffers
• Revegetate any area affected by drainage, stormwater, irrigation or channelisation works	Revegetate any area affected by drainage, stormwater, irrigation or channelisation works	• Revegetate any area affected by drainage, stormwater, irrigation or channelisation works

Embankments, berms and levee banks

Zone A	Zone B	Zone C
• All embankments, berms and levee banks to conform to contours of surrounding landscape	• All embankments, berms and levee banks to conform to contours of surrounding landscape	• Embankments, berms and levee banks to conform to contours of surrounding landscape where possible
• All embankments, berms and levee banks to be planted with species evident in surrounding landscape	• All embankments, berms and levee banks to be planted with species evident in surrounding landscape	• Embankments, berms and levee banks to be planted where possible

Water contamination and turbidity

Zone A	Zone B	Zone C
• Avoid water contamination and turbidity of the wetland using land-based absorption methods for stormwater disposal	• Minimise water contamination and turbidity of the wetland using land-based absorption methods for stormwater disposal	• Minimise water contamination and turbidity of the wetland using land-based absorption methods for stormwater disposal

Timber harvests and plantations

Zone A	Zone B	Zone C
• No timber harvests allowed unless inevident	• Timber harvests (40 ha) permitted but substantial vegetative buffers maintained • No timber harvesting on the skyline	• Timber harvests (40 ha) permitted but vegetative buffers maintained • No timber harvesting on the skyline
• No softwood plantations	• No softwood plantations	• Softwood plantations to be sensitively sited and designed

3.6 REFERENCES

Beilharz, M.I., 1989. Conservation Value Assessment of Wetlands, Discussion Paper. Wetlands Unit, Department of Conservation and Environment, Melbourne.

Brown, T.J. and Itami, R.M., 1982. Landscape Principles Study-Procedures for Landscape Assessment and Management-Australia. Landscape Journal 1 (2).

Clark, I.D., 1989. Themes Relating to the past 150 Years of Victoria's Rivers, Streams, and Water Systems. A report to the Land Conservation Council, Melbourne.

Clark, J.D., and Itami, R.M., 1990. Timber Harvesting and Visual Resource Management, A Revised Report for Phase II. School of Environmental Planning, Melbourne.

Corrick, A.H., 1981. Wetlands of Victoria II. Wetlands and Waterbirds of South Gippsland. Proceedings of Royal Society of Victoria 92:187-200.

Corrick, A.H., 1982. Wetlands of Victoria III. Wetlands and Waterbirds between Port Phillip Bay and Mount Emu Creek. Proceedings of Royal Society of Victoria 94 (2):69-87.

Corrick, A.H., and Cowling, S.J. 1975. A Survey of the Wetlands of Kerang, Victoria. Fisheries and Wildlife Paper, Victoria Number 5. Fisheries and Wildlife Division, Victoria.

Corrick, A.H., and Norman, F.I. 1980. Wetlands of Victoria I. Wetlands and Waterbirds of the Snowy River and Gippsland Lakes Catchment. Proceedings of Royal Society of Victoria 91:1-15.

Department of Conservation and Environment. Proceedings of the Workshop on Conservation Value Assessment of Wetlands, Bendigo, 14-15 September 1989.

Department of Conservation, Forests and Lands, 1990. Proposed *Barmah* Management Plan, *Barmah* State Park, *Barmah* State Forest. Melbourne.

Department of Conservation, Forests and Lands, 1988. Wetlands Conservation Program for Victoria. Melbourne

Forests Commission, Victoria, 1981. Visual Absorption Capability in the Blue Range Study Area: an assessment procedure for Victoria's forest landscapes. Melbourne.

Gehlbach, F. R., 1974. Investigation, Evaluation, and Priority Ranking of Natural Areas. Paper presented at the symposium, The Natural Areas of Texas, sponsored by the Texas Academy of Science, 1 March 1974. Biol. Consery (8) (1975), Applied Science Publishers Ltd, England, 1975.

Gobster, P. L. and Chenoweth, R. E., 1989. The Dimensions of Aesthetic Preference: A Quantitative Analysis. Journal of Environmental Management 29:47-72

Goodrick, G. N., 1984. Mapping and describing wetlands in arid NSW: an application of the landscape approach. In: Myers, K., Margules, C.R. and Musto, I. (eds). Survey Methods for Native Conservation, Vold, Proceedings of a Workshop held in September 1983 at Adelaide University, Canberra. pp 267-274.

Gould League, 1989. Wetlands Wildlife, The Nature of Wetlands in Southern Australia. Gould League of Victoria Inc., Melbourne.

Leonard, M., and Hammond, R., 1984. Landscape Character Types of Victoria, With Frames of Reference for Scenic Quality Assessment. Forests Commission Victoria.

McComb, J., and Lake, P.S. (eds). The Conservation of Australia's Wetlands. Surrey Beatty / World Wildlife Fund, Melbourne.

New Zealand Ministry for Works and Development, 1987. *Visual Assessment Method for Planning, An Introductory Guide.*

Office of the Commissioner for the Environment, 1988, *State of the Environment Report 1988, Victoria's Inland Waters,* Melbourne.

Pressey, R. L., 1984, A method for description and evaluation of coastal floodplain wetlands. In: Myers, K., Margules, C.R. and Musto, I. (eds). *Survey Methods for Native Conservation,* Vol. 1, Proceedings of a Workshop held in September 1983 at Adelaide University, Canberra.

Sargent, F.O., and Brande, J.H., 1976. Classifying and evaluating unique natural areas for planning purposes. *Journal of Soil Water Conservation,* May—June.

Scenic Spectrums, 1986a. *A Preliminary Scenic Assessment Procedure for Australia's River Landscapes.* Prepared for the Victoria National Estate Committee, Melbourne.

Scenic Spectrums, 1986b. *A Review of Previous Studies of the Scenic Assessment of Rivers, Annex I to A Preliminary Scenic Assessment Procedure for Australia's River Landscapes.* Prepared for the Victoria National Estate Committee, Melbourne.

Sinden, J., 1990. *Valuation of Unpriced Benefits and Costs of River Management.* Prepared for Department of Water Resources.

Smardon, R.C., 1977. *Research Strategy for Assessing Visual Impact from Management and Land Development Activities on Wild and Scenic Rivers.* Presented at the Scenic Rivers Symposium, June 17-18, 1977, Louisiana State University, Baton Rouge, Louisiana.

Smardon, R. C., (ed) 1983. *The Future of Wetlands, Assessing Visual-Cultural Values.* Allanheld Osmun and Co Publishers, Inc, USA.

Smardon, R.C. Visual *Access to 1,000 Lakes, in Landscape Architecture,* May — June

Tans, W., 1974. Priority Ranking of Biotic Natural Areas. Scientific Areas Preservation Council, Wisconsin Department of Natural Resources, Madison. *The Michigan Botanist* 13.

Williamson, D.N., and Calder, S.W., 1979. Visual Resource Management of Victoria's Forests: A New Concept for Australia. *Landscape Planning* 6:313-341. Elsevier Scientific Publishing Company, Amsterdam.

Zube, E.H., And Mills, L.V., Jr, 1976. Cross-Cultural Exploration In Landscape Perception. In Zube, E.H. (Ed). *Studies In Landscape Perception.* Amherst: University Of Massachusetts, Institute For Man And Environment.

3.7 APPENDICES

Appendix 3a Potential scenic assessment characteristics

Topographic or landform dimensions:
- Slope steepness
- Relative relief
- Topographic enclosure
- Spatial diversity (topographic complexity)
- Topographic form (ruggedness)
- Prominent or unique forms (peaks, terraces, valleys, etc)

Geologic dimensions:
- Rock outcrops
- Cliffs
- Gorges and canyon walls
- Volcanic cones
- Stoney rises
- Faults
- Unique geologic materials

Vegetation dimensions
- Vegetation structure (height and density)
- Vegetation type (species or association)
- Vegetation patterns (diversity)
- Vegetation edge effects (contrast, transition)
- Percentage tree cover
- Unique flora species

Waterform dimensions:
- River size (depth width)
- Channel pattern (fixed, braided, branched, or looped meander)
- Depth variability
- Floodplain width
- Bank height
- Water prominence
- Water clarity
- Water colour
- Tributaries (number and size)
- Flow characteristics and features:
  —stream velocity (gradient)
  —pools and riffles
  —deep water holes
  —rapids
  —cascades
  —waterfalls
  —sloughs and backwater
- Associated features:
  —billabongs
  —islands
  —sand bars

  - beaches
  - swamps, bogs and marshes
  - dry channels
  - lakes in floodplain

Wildlife dimensions:
- Wildlife types (aquatic, terrestrial, arboreal)
- Wildlife diversity (aquatic, terrestrial, arboreal)
- Significant spawning, nesting or mating areas
- Rare or endangered species habitat

Land-use alteration dimensions:
- % developed lands
- % natural forests or grasslands
- % coniferous plantations
- european deciduous forests
- % agricultural (grasslands and croplands)
- % residential
- % industrial
- % commercial
- Degree of alteration dominance for
  - buildings and structures
  - roads
  - powerlines
  - pipelines
  - towers
  - timber harvests
  - agricultural clearings
  - exotic plantations
  - dam walls
  - canals
  - quarries and mines
  - exposed soils
  - channelisation

Access dimensions:
- Existing paved roads
- Existing unsealed roads
- Planned roads
- Public easements
- 4WD tracks
- Walking tracks

Cultural/archaeological dimensions:
- Archaeological sites
- Historic sites
- Historic tracks, roads and railways
- Historic settlements
- Unique architectural structures

Abstract dimensions:

- Degree of naturalism
- Land-use compatibility (unity)
- Landcover diversity
- Vegetation diversity
- Sense of place
- Landscape integrity
- Visual absorption capability

Viewshed dimensions:

- Topographic viewshed
- Vegetative viewshed
- Distance zones (foreground, middleground, background)
- Area of view
- Location of viewing points and corridors
- Observer volumes or public sensitivity levels
- Number of observer locations.

Source: Scenic Spectrums (1986b), A review of previous studies of the scenic assessment of rivers, Annex 1 to *A Preliminary Scenic Assessment Procedure for Australia's River Landscapes,* prepared for the Victoria National Estate Committee, Melbourne

Appendix 3b Wetland setting category descriptions

Setting Category	Description
Natural wetland settings	Wetland settings in which both the immediate wetland zone and the surrounding viewshed are free from visually apparent alterations to the landscape. The wetland is free from channelisation or impoundments and the area is generally inaccessible except by walking tracks
Semi-natural wetland settings	Wetland settings in which visual alterations in the immediate wetland zone and surrounding viewshed may be visually apparent but not dominant. Alterations, dam walls and diversions may exist, but are isolated and limited in the extent of their visual dominance. Limited road or railway access may exist, but extensive vehicular access systems are lacking, especially adjacent to the wetland
Farm—forest wetland settings	Wetland settings in which the immediate wetland zone and surrounding viewshed are likely to contain a number of visually dominant alterations within a landscape of generally less intense alteration. The landscape within the immediate wetland zone reflects an inter-mixing of predominantly native forest or scrub and agricultural land uses. Alterations, diversions and small farm dams occur with moderate frequency. Vehicular access to and along the wetland is moderately established but of relatively low visual impact
Agricultural wetland setting	Wetland settings in which dominant landscape alterations exist due to a transformation of the natural landscape for agricultural uses. Improvements, diversions, canals and channelisations and small to large farm dams occur with moderate to high frequency. Remnant vegetation remains, but may be restricted to streamside reserves and or tree rows along fencelines. Farm buildings and structures occur frequently. Vehicular access to and along the wetland may be very well established with both unpaved and paved tracks and roads
Tourism/ recreational wetland settings	Wetland settings in which visual alterations are dominant due to the transformation of the natural landscape for tourism or recreational purposes. Structures such as lookouts, ski-tows, accommodation units and other recreational facilities occur with moderate to high frequency. Remnant vegetation exists adjacent to these structures but cleared areas may be dominant. Vehicular access to and along the wetland may be very well established with both paved and unpaved tracks and roads
Small town-suburban wetland settings	Wetland settings in which visual alterations are frequent and apparent to dominant within small town and suburban residential zones of metropolitan areas. Land use is primarily low to moderate density residential with limited commercial and light industrial uses. The wetland may also flow through parks and undeveloped areas. A high level of vehicular access on paved and unpaved roads to and along the wetland
Urban-industrial wetland settings	Wetland settings in which alterations are highly dominant within high urban and industrial land uses. Land uses may from high density residential and commercial zones to heavy industrial zones. use parklands and recreation facilities also occur. The wetland is likely to be highly controlled and modified along most of its length. Vehicular access to and along the wetland may be intense. Transportation systems and utilities frequently cross or create barriers along the wetland

Source: Adapted from River Setting Category Descriptions, Scenic Spectrums, 1986a. *A Preliminary Scenic Assessment Procedure for Australia's River Landscapes.* Prepared for the Victoria National Estate Committee, Melbourne

Appendix 3c Notes on wetland categories

'Flooded river flats' include many areas of agricultural land which become temporarily inundated after heavy rains or floods. Water may be retained in local depressions for just a few days or for several months. Despite their temporary nature, wetlands in this category provide valuable feeding and breeding habitat for many waterbirds.

'Freshwater meadows' include shallow (up to 0.3 m) and temporary (less than four months duration) surface water, although soils are generally waterlogged throughout winter. Such meadows commonly occur on grazing land.

'Shallow freshwater marshes' are usually dry by mid-summer and fill again with the onset of winter rains. Soils are waterlogged throughout the year and surface water up to 0.5 m deep may be present for as long as eight months.

The above three categories have been and remain under greatest threat, because:

- they are shallow, ephemeral and often easily drained;
- they are often adjacent to good quality agricultural land, and, consequently, drainage can improve grazing land around their margins.

'Deep freshwater marshes' generally remain inundated to a depth of 1-2 m throughout the year.

'Permanent open freshwater' wetlands are usually more than 1 m deep and therefore deeper than wetlands of other categories; they can be natural or artificial.

'Saline wetlands' are those in which salinity exceeds 3000 mg/L throughout the whole year.

'Semi-permanent saline' wetlands may be inundated to a depth of 2 m for as long as eight months each year.

'Permanent saline' wetlands include coastal wetlands and parts of intertidal zones.

'Sewage oxidation basin' and 'salt evaporation basin' include artificial wetlands used for sewage treatment and salt concentration respectively. Both provide habitats for waterbirds.

Source: CFL *et al.* 1988. *Wetlands Conservation Program for Victoria.* Department of Conservation, Forests and Lands, Melbourne. p. 7.

WATER MANAGEMENT

4.1 INTRODUCTION TO WETLAND WATER MANAGEMENT

The vital physical, chemical and biological functions which give wetlands their unique character and habitat value are driven by water availability. As well as being maintained by hydrologic processes, wetlands originate from hydrologic processes, for example, in the way billabongs are formed when a river changes its course. Also, in their role as flood storage areas, wetlands are a vital element of the catchment hydrological system.

Wetlands naturally alter in character over time, in response to either gradual climatic change, or catastrophic hydrologic events such as large floods. However, human disturbance of hydrological processes has very rapidly resulted in the degradation or loss of many wetlands. Wetland hydrology can be altered directly by drainage and artificial inundation, or indirectly by river channel modification, catchment deforestation, rising watertables from irrigation and river regulation.

Managing the hydrology of wetlands that have important conservation values involves ensuring that the existing hydrological processes are maintained. It is a common situation to have ongoing pressures which alter the hydrology. Modelling of the system produces a useful tool for predicting future changes under a given scenario, and searching for alternatives if the predicted changes are considered undesirable. Given the widespread loss and degradation of wetlands caused by drainage and flow regulation over the past century, it may be desirable and feasible in some locations to rehabilitate wetland functioning.

There are two main approaches to this problem:

1 hydrology-driven
2 ecology-driven.

The hydrology-driven approach attempts to define and reinstate the hydrological regime as it existed at some previous time, or in the absence of the degrading influences (Gutteridge, Haskins and Davey Pty Ltd 1991a, Beovich and Lloyd 1993a, 1993b, Nathan 1992, Gippel and Finlayson 1993). Implicit in this approach is the assumption that provision of a natural hydrological regime will encourage ecological recovery to something resembling the condition that applied prior to disturbance (this is often unknown). The alternative, ecology-driven approach attempts to encourage development of either preferred biological communities, or those that were assumed or known to previously exist (Crome 1988, McCosker and Duggin 1993, Keyte 1994). This approach applies knowledge of the relationships between hydrological regime and ecological response, generated either through controlled experiment or field observations.

In some cases, wetland water requirements have been arbitrary estimates (Brereton 1993). In the case of Hirds and Johnsons Swamps, Victoria (NRE undated), although granted an allocation of water to maintain ibis breeding and duck habitat, water has been supplied on the basis of cost, rather than ecological requirements (Kinhill Engineers Pty Ltd 1988). Some recommendations for wetland watering have combined aspects of the natural flow regime with the known requirements of particular species (Briggs 1988, Kinhill Engineers Pty Ltd 1988, Bennett and Green 1993, Thornton and Briggs 1994). Bennett and McCosker (1994) found that the hydrology-driven and ecology-driven approaches to determining water requirements of the Gwydir Watercourse produced similar results.

Defining the natural hydrological condition is not a simple matter. The ideal of providing high value wetlands with hydrological conditions that would prevail in the absence of human impact is unrealistic. Many wetland environments that are highly valued for their naturalness are in fact the product of lengthy human interference. For example, initiation of the development of the peat mires which blanket parts of the British Isles and Scandinavia is thought to be related to hydrological changes that followed woodland clearance by prehistoric people (Moore 1975). It is thought that the unique River Redgum (Eucalyptus camaldulensis) forests along the River Murray developed after European settlement, when they replaced savanna woodland vegetation that was maintained by regular Aboriginal firing (Jacobs 1955). Alteration of the hydrological regime of the Murray River has created additional permanent wetlands that have high value as drought refuges in this semi-arid environment (Jensen et al. 1994). The floating islands of Lake Pirron Yallock are so unusual that they have high conservation status, but the islands and lake were formed artificially as a result of road construction modifying the hydrology of an intermittent wetland system (Gippel 1993). In Australia, the natural regime is usually understood to mean that which prevailed just prior to European settlement, or that which would exist today if the major cultural factors that currently alter hydrology (eg regulating impoundments or artificial levees on rivers) were removed.

This chapter states the importance of hydrology to wetland functioning, outlines the main hydrological processes that operate in wetlands, and reviews published literature on modelling wetland hydrology. Techniques of hydrological analysis suitable for assessing the water requirements of wetlands are described. The techniques can be applied to determine the natural and, if modified, the current hydrologic regime. Wetland hydrology can be characterised by analysing hydrologic records or, if these are absent, by modelling hydrologic processes. In some situations hydrological modelling is not possible or feasible. The water requirements of some key wetland plant species and communities are discussed briefly. In many cases, management will involve a degree of manipulation of water levels, and some techniques of achieving this are suggested.

4.1.1 Wetland definition and classification

Various systems of definition and classification have been developed for the purpose of inventorying wetlands. The US Fisheries and Wildlife Service adopted a definition that emphasises three key wetland attributes: hydrophytic vegetation;

hydrology (flooding during the growing season); and hydric soils (periodically inundated and/or saturated) (Burke *et al.* 1988). The most important aspect of this definition is that soils should be inundated during the growing season. Inundation severely limits or prevents the availability of oxygen to plant roots. These conditions allow the growth of plants and animals that are adapted for life in saturated soils, and stress or eliminate those that are not.

Unaltered sites that have hydric soils and wetland vegetation are assumed to possess wetland hydrology, but extensive modification of hydrologic cycles means that wetland hydrology no longer exists on many sites that were originally wetlands. Legislation to protect wetlands in the USA requires that the existence of a wetland be defined in precise hydrological terms. It appears that a minimum of between 14 and 28 days of saturation near the surface are required to induce anaerobic conditions and hydric soil morphology (Skaggs *et al.* 1994). Thus, proposed criteria for minimum wetland definition require that the watertable is at or less than a critical depth from the surface for a minimum number of consecutive days during the growing season (Skaggs *et al.* 1994). The systems used for wetland classification in the USA and Canada have hierarchical structures that at the lowest level rely mainly on vegetation characteristics (Carter 1986). Some important attempts have been made at classifying wetlands on the basis of hydrological characteristics alone, but data and knowledge gaps currently limit their application (Carter 1986).

In Victoria, the definition and classification of wetlands grew out of early survey work by Corrick (1981, 1982) and Corrick and Norman (1980). Wetlands were defined as areas (natural or human constructed) temporarily or permanently inundated with water. For practical reasons the wetlands less than 1 ha in area, marine habitats below mean low tide, rivers, bogs and heaths, reservoirs and artificial water supply and drainage channels were excluded. For some purposes, these excluded areas can still be regarded as wetland environments, but management is problematic because there is little information available on their distribution.

Corrick (1981, 1982) classified wetlands initially on the basis of vegetation, water regime (permanence), depth, salinity and area, and then allocated to subcategories on the basis of vegetation important in determining use by waterbirds. Mapping of wetlands in Victoria is now complete and the information is held on a database at the Arthur Rylah Institute, Department of Natural Resources and Environment.

The characteristics and distribution of wetlands in Australia are described in McComb and Lake (1988) and DCE and Office of the Environment (1992). Hydrological characteristics are covered in these documents, but regimes and processes are not described in great detail. These publications also document wetland losses, which have been considerable. About 28% of the area, and 22% of the number of wetlands in Victoria have been lost since European settlement (DCE and Office of the Environment 1992). Much of the loss has been associated with hydrological disturbance, with drainage accounting for 55% of the changes. Shallow wetlands have suffered the greatest losses due to their ease of drainage. Change in hydrological regime due to less permanent watering (flow and channel regulation, lowered watertables and partial draining) accounts for 40% of wetland change. More permanent watering regimes have been responsible for 5% of the change. Salinity is a major problem in regions to the north of Victoria, but it has been responsible for loss of only 1% of wetlands (DCE and Office of the Environment 1992)

Special definitions have been applied to wetlands with high conservation status. These definitions are important because such wetlands have been, and are likely to remain, the main targets of management programs aiming to protect or enhance hydrological processes. CFL *et al.* (1988), and Shaw *et al.* (1990) identified criteria that could be used to grant a wetland high conservation status. Some of the main criteria are that the wetland:

- is designated or nominated in a Government policy statement or agreement, or an international treaty;
- supports large or diverse populations of waterfowl; supports a rare or endangered species of plant or animal;
- is a rare example of wetland type; or
- is in pristine condition.

Tunbridge and Glenane (1982) based assessments of wetland value on fish populations. The Wetlands Resource Assessment Package (WRAP) (Australian Biological Research Group undated) places most emphasis on the presence of rare or threatened species and has been applied in some areas of Victoria. For wetlands in the Kerang area, Lugg *et al.* (1989) used a greater range of criteria to allocate wetland value as high, moderate or low. High value appears to derive mainly from consideration of ecological characteristics. Carter (1986) argued that high value should be assigned to wetlands if they perform a significant role in basin-wide hydrological processes.

4.1.2 Wetland hydrological processes

It has been stressed repeatedly that knowledge of hydrology is basic to the understanding of all wetland processes (Greeson *et al.* 1979, Good *et al.* 1978). The role of hydrological processes in wetland functioning has been described by Gosselink and Turner (1978) and Gilman (1994).

The main hydrological considerations applying to wetlands are:

- water budgets,
- physico-chemical processes,
- water regimes,
- hydrodynamics,
- basin-wide hydrologic influences, and
- hydrological-biological interactions.

These are briefly described below.

Water budgets

Development of a water budget is fundamental to most wetland hydrological modelling (Dooge 1975). A water budget is necessary for estimating wetting and drying cycles, estimating the volumes of water that need to be managed, and for calculating nutrient and other chemical budgets. A basic wetland water budget calculates the change in storage as a simple function of inputs of precipitation, surface runoff and groundwater and outputs of evapotranspiration, groundwater, surface runoff. The budget is calculated on a time step limited by data availability or appropriate to the objectives of the investigation. Water budgets are simple input-output models that can be developed on a spreadsheet. This approach is not concerned with water flow-paths or velocities.

The main problem in developing a water budget model lies in measuring or estimating the various components. Only a few studies have considered all components of the budget (eg Woo and Rowsell 1993, Gippel 1993). Groundwater is particularly difficult to include, and for this reason is often ignored or represented merely as the residual term of the equation (Duever 1988a, LaBaugh 1986). Unfortunately, there are large errors associated with the measurements or estimates of the individual components of the budget (Winter 1981), and the residual term will contain the sum of all these errors. Van der Molen (1988) describes studies which have developed water budgets. Duever (1988a) also details the various techniques available for measuring or estimating the water budget components.

Physico-chemical processes

Wetland water chemistry is a function of the quality of the inflowing water and the interaction of water with wetland soils and vegetation (Kadlec and Kadlec 1978, Klopatek 1978). Understanding these chemical processes (which essentially deal with water-borne substances) requires an understanding of hydrological processes. Chemical and nutrient budgets need a reliable water budget, but this has been a weakness of most studies so far (Kadlec and Kadlec 1978, LaBaugh 1986, Carter 1986).

Wetland chemistry is very dependent on the temporal aspects of hydrology (Briggs *et* al. 1985, Serrano 1992), so its investigation requires a model with an appropriate time step. Water quality also depends on the source of the inflowing water (Schot *et al.* 1988), so the hydrological budget should separate rainfall, groundwater and surface water contributions. Numerical models of varying levels of sophistication have been developed linking hydrology with aspects of water quality (Brown 1988, Mitsch and Reeder 1991).

Water regimes

The seasonal and year-to-year variations in rainfall and runoff produce natural cycles of water level fluctuation in wetlands. The amplitude and degree of variation is a function of runoff variability [which is known to be high in Australia (Finlayson and McMahon (1988)], but this will be damped if there is a strong link with the groundwater system. Definition of the water regime, or mean temporal pattern of water levels, requires either a long time series of water level observations, or data that will enable this to be modelled (Duever 1988a, Duever 1988b).

The water regime can be described in terms of the frequency, duration and depth of inundation. The underwater light field is a function of water depth (and turbidity and colour), so inundation depth is an important determinant of vegetation success in wetlands (Squires and van der Valk 1992). In Corkscrew Swamp, Florida, Duever (1988b) found that the maximum wet season water level and minimum dry season water level partly explained the distribution of plant communities. However, the hydroperiod, defined as the duration of the annual period of inundation, was a more significant determinant. Duever (1988b) explained that the existence of anaerobic soil conditions is the most important factor controlling the distribution of wetland communities; the mere presence of water above the soil surface significantly limits the movement of air into the soil, and the longer this exchange is reduced, the more severe is the depletion of oxygen.

Water depth does not vary greatly in areas of flat terrain, so spatial vegetation patterns are more likely to be a function of hydroperiod. Minimum and maximum water levels will be more important in areas with strong relief, where water levels cover a greater range, and flooding is more ephemeral (Duever 1988b).

Brownlow et al. (1994) pointed out that the bulk of the literature emphasising the importance of water depth on the performance of aquatic macrophytes has emanated from temperate climates where the seasonal fluctuations in water level are typically small. In semi-arid regions, or areas of highly variable hydrology (eg many areas of Australia), the variation in water levels is a more important determinant of species distribution. Brownlow et *al.* (1994) developed an index of water regime that describes the seasonal pattern of duration for a range of depth classes.

Duever (1988a) cited evidence that floodplain wetlands are relatively insignificant in rivers of less than order five. In higher order rivers the hydroperiod is typically within the range 2–6 months, but climate and latitude exert a strong influence on the water regime. Prior to regulation, wetlands of the River Murray region had natural flood durations ranging from 2.5 months at Lake Moodemere to 9.3 months for Barmah Forest rushlands (Atkins 1993).

Inundation frequency is of particular importance in riverine wetland systems. Overbank floods link floodplain wetlands with the adjacent river (Junk et *al.* 1989). Many ecological processes are triggered or facilitated by floods and the timing of the event can be of crucial importance (Lloyd et *al.* 1991). A partial flood series analysis of records from gauging stations on the Goulburn river, prior to its regulation, revealed that floods just sufficient to overtop the banks and flood nearby wetlands (minor flood) occurred on average every 1.0–1.2 years (Gippel and Finlayson 1993). Prior to its regulation, the lower Thomson River experienced a minor flood every 1.4 years (Gippel and Stewardson 1995).

Hydrodynamics

Most wetland hydrological models make the simplification that water levels respond instantly and uniformly to inflow and outflow. This is not a problem in small wetlands, but important chemical and biological processes may operate within the long hydrological response time scales of large systems. While a uniform water surface may exist at high flood levels, during the rising and recession limbs, river and wetland levels are likely to be different (Carter 1986). Large floodplain wetlands will only partially fill in response to short duration river flood events. Knowledge of the hydraulics of the wetlands will enable prediction of the extent of inundation.

Hydrodynamic models are used to simulate unsteady flow. Such models have much greater data demands than simple budget approaches. Information is required on inflow stream hydrographs, the wetland topography and hydraulic characteristics, and in the case of floodplain wetlands, the hydraulic characteristics of the river to wetland connections. If flow records are inadequate then hydrological modelling will be necessary. Modelling shallow flow over surfaces with large-scale roughness, such as occurs in heavily vegetated wetlands, is a difficult problem.

Hopkinson and Day (1980b) developed a wetland hydrodynamic model using a finite element approach to solve the equations of motion and continuity. The model suitably predicted inputs, outputs and volumes stored, but predicting velocities was not one of the model's strengths. Schouten *et al.* (1988) described a similar type of model.

Hydrodynamic models can be used to route flows through the complex hydraulic interconnections that link large wetland systems (Wong and Wellington 1990, Gutteridge, Haskins and Davey Pty Ltd 1991a, 1991b, Bewsher *et al.* 1991). Some studies have used remote sensing to establish the relationship between the extent of floodplain inundation and river discharge (Dwyer and Bennett 1988, Blasco *et al.* 1992, Bennet and Green 1993).

Velocity distributions in wetlands can be modelled using a hydrodynamic approach. Low velocities can generally be expected in wetlands (<1 cm/s) because of gentle gradients and drag from dense vegetation (Duever 1988a). However, flow velocity affects sediment movement and organic matter output, and subtle spatial velocity differences can strongly influence the pattern of productivity (Gosselink and Turner 1978). Coates *et al.* (1989) used a hydrodynamic approach to model the scour of sediment from a tidal wetland.

Basin-wide hydrologic influences

Wetlands are an important component of the catchment hydrological system (Carter 1986). They act as storage areas for flood water, thereby reducing the magnitude of floods downstream, and in some cases desynchronizing flood peaks. Carter (1986), Novitzki (1978) and O'Brien (1988) cite evidence that flood peaks can be up to 80% lower in basins with wetlands covering around 20% of the area, compared with basins that have little or no wetlands present.

Wetlands reduce the velocity of flood waters and this promotes the deposition of nutrient laden sediment (Hindall 1975, Boto and Patrick 1978). Novitzki (1978) reported that sediment loads are 90% lower in basins containing 40% lake and wetland area than in basins with little or no lake and wetland areas.

Because of the prevalence of fine-grained impervious substrates, it is thought that most wetlands generally have only minor interaction with the groundwater system (Duever 1988a). Most observations suggest that where wetlands are linked to the groundwater system they mainly act as discharge areas (Burke *et al.* 1988, Duever

1988a, Schouten et al. 1988). Some wetlands can act as recharge areas (Siegel 1988), while in other cases wetlands alternately discharge and recharge groundwater (Carter 1986). Floodplain wetlands which discharge to the adjacent stream can have a large influence on baseflow levels (O'Brien 1988).

Hydrological–biological interactions

Ehrenfeld and Schneider (1991) found that changes in water quality were more important in determining changes in community composition and structure than were changes in hydrology. In a wetland in The Netherlands, the groundwater, surface flow and rainwater had such distinctive chemical compositions that the spatial vegetation patterns tended to reflect water source (Schot et *al.* 1988). However, it is more common for biological (especially vegetation) distributions in wetlands to reflect the pattern of water level variation. The relationships can be sufficiently distinct to permit estimation of flood characteristics by evaluation of the species composition (Bedinger 1978).

Many studies have observed strong relationships between hydrological regime and the distribution of key vegetation species or communities (Briggs and Maher 1985, Bren and Gibbs 1986, van der Valk 1987, Denton and Ganf 1994). Water regimes also influence the distribution of algae (Casanova 1994) and bacteria (Boon 1990, 1991). Inundation events lead to distinctive behavioural responses by macroinvertebrates (Boulton and Lloyd 1992), waterbirds (Briggs et *al.* 1985) and fish (Lake 1967a, 1967b, Arumugam and Geddes 1987, Gehrke 1990, Lloyd et *al.* 1991).

Wetland vegetation zonation may partly reflect variations in soil types, but ultimately, the floristic composition and community structure is dependent on water regime (Carter 1986). For example, on the Murray River, Victoria, a common sequence from high to low elevation is zones dominated by Box, River Redgum, Spike Rush, Moira Grass, Tall Spike Rush and Giant Rush (Ward et *al.* 1994). The structure of such plant communities exerts a strong influence on the distribution and abundance of wetland fauna (Wong and Roberts 1991).

Wetlands subject to sheet flow of well mixed water over uniform topography tend to have large monospecific stands of vegetation. In contrast, a variable hydrological regime, in association with elevational and substrate differences, increases species diversity (Duever 1988a, Kallemeyn et *al.* 1988). Vegetation diversity generally increases with wetland elevation and is therefore a function of flooding duration and depth (Duever 1988a). Diversity also increases with increasing velocity (Heinselman 1970).

Wet periods, when wetlands are fully or partially inundated, are obviously necessary for normal wetland functioning, but occasional dry periods are also important. During dry periods desiccation of organic matter releases nutrients which produce a flourish of biological activity when the wetland is refilled. A number of waterbirds, fish and amphibians are stimulated to breed by the sharp rise in water level which signals availability of an abundance of food following the drying cycle (Lloyd et al. 1991).

4.1.3 The need for wetland water management

Australia has national and international commitments to protect important wetlands (McComb and Lake 1988, Michaelis and O'Brien 1988). Wetlands that are recognised by the Ramsar Convention, Japan-Australia Migratory Birds Agreement, the China-Australia Migratory Birds Agreement and the Register of the National Estate, have important, representative, unique or outstanding features, and their protection fundamentally depends on maintenance of hydrological processes.

Water management is important for wetlands because:

1. normal wetland functioning fundamentally depends on hydrologic processes, so wetland conservation ultimately relies on protection of the hydrologic regime, and
2. disturbance to hydrologic processes is the greatest current threat to wetland conservation values, and historically has caused most wetland degradation. Wetland restoration and protection will therefore usually involve consideration of hydrologic issues.

4.1.4 Strategies for wetland management

While water is the key consideration in wetland management, knowledge of wetland hydrology is incomplete (Carter 1986, LaBaugh 1986). Kusler (1987) correctly pointed out that this is a poor excuse for hesitancy and inaction, and more is known about wetland hydrology than is currently being applied.

Kusler (1987) suggested several general strategies for wetland managers to approach hydrologic issues. Managers should:

- aim to protect the natural hydrologic regime as the first priority, on the presumption that other wetland functions will restore naturally;
- realise that wetlands are part of a larger system, such as an adjacent river, and cannot be managed as a separate entity; and
- presume that all natural hydrologic parameters are important to the functioning and long-term existence of the wetland.

Hydrologic investigations should consider the role of extreme as well as average hydrologic events, and recognise that there are margins of error and limits to precision in hydrologic studies. Management planning should approach areas of uncertainty conservatively, and accept that hydrological management may initiate unexpected or undesirable changes in some functions, but that within a certain range, such changes may be essential to the long-term existence of the wetland.

The idea of an unmanaged, natural hydrologic regime is intuitively consistent with the ethic of nature conservation, but Wong and Roberts (1991) point out that this may not be the optimum approach for management of wetlands and the catchment as a whole. Where there is competition for a limited water resource, the aim should be to maximise the efficiency of water distribution. Managers should seek to develop strategies which satisfy competing demands without compromising the biological integrity of wetlands.

From a conservation standpoint, reinstatement or protection of the natural hydrologic regime is ideal, but different individuals, authorities and community interest groups have different uses for wetlands. The wetland water management strategy will ultimately depend on agreed land use priorities, ideally established by consultation with the various interest groups (Wong and Roberts 1991).

4.1.5 Developing a wetland water management plan

Hydrological investigation

The hydrology of a wetland is determined by first assessing the relative contributions of the various inputs and outputs, and then ascertaining the timing of these contributions. Established hydrological techniques are available for this purpose, ranging from simple reconnaissance methods to sophisticated numerical models. The choice of technique will be determined by the type of wetland, time available, and budget constraints.

Determine the natural regime

A common hydrologic problem in wetland management is determining the natural hydrologic regime of disturbed wetlands. The basic procedure for solving this problem is to first obtain information on the nature of the disturbances, and then analyse historical hydrologic records where available, or undertake modelling studies, to determine the natural and current water regime.

Investigate options for altering the hydrological regime

Options could be removing the source of disturbance, installing regulators, or requesting water allocations or environmental flows. In cases where the current regime is adequate, any potential threats to the water supply should be identified.

Devise a plan which best satisfies the management objectives

The objectives will depend on the wetland's value for conservation, recreation, agriculture, or some other land use. The water requirements of some wetland uses conflict, and priorities will have to be established. For particularly high value wetlands it may be necessary to protect conservation values at the exclusion of other interests. After weighing the costs, benefits and practicalities of the various management alternatives, a preferred option is selected, and plans developed accordingly.

4.2 KEY HYDROLOGICAL FEATURES

4.2.1 Wetland water budget

A water budget is a simple model of the inputs and outputs of water to a wetland (Carter 1986, LaBaugh 1986, Suurballe 1987, Duever 1988a) (Figure 4a), such that over a specified time interval (t):

$$DS(t) = P + Q_1 + G_1 - E - Q_O - G_U + e$$

where:

DS = change of water quantity stored in the wetland

P = precipitation falling on the wetland
Q_i = surface water flowing into the wetland
G_i = groundwater flowing into the wetland
E = evapotranspiration volume
Q_o = surface water flowing out of the wetland
G_υ = groundwater flowing out of the wetland
e = error term

In most areas the inputs and outputs tend to vary seasonally and this gives rise to seasonal variations in the depth of water in wetlands. fluctuations in water level also occur within seasons, in response to more frequent and erratic inputs. In the longer term, the water level may be low or high for unusually long periods, or at unseasonal times, in response to unusual weather patterns or extended wet or drought years.

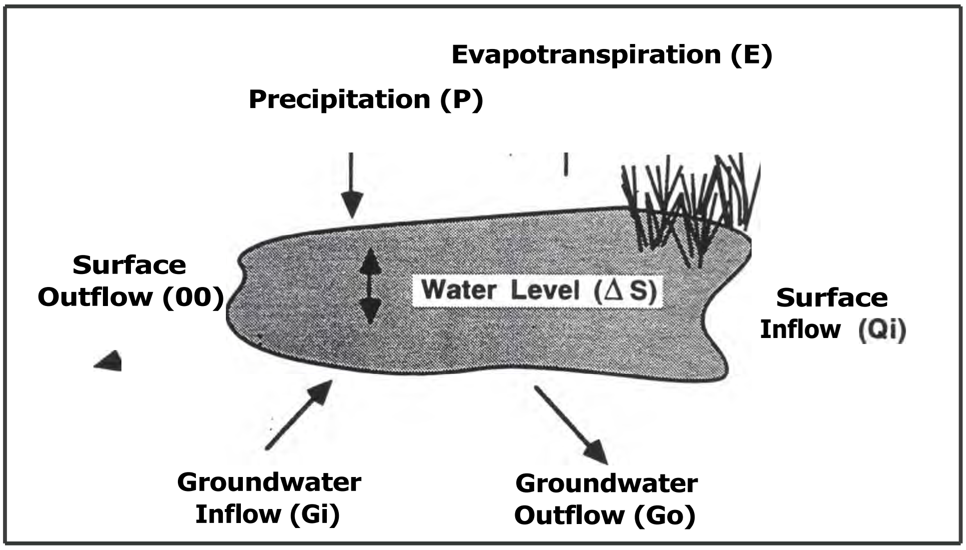


Figure 4a Simple elements of a wetland water budget

The crucial information required for wetland management is knowledge of the typical pattern of water level variation through time. This pattern can be characterised in terms of the frequency of wet and dry periods, the average and extreme duration of wet and dry periods, and the seasonality of wet and dry periods. Because the Australian climate is typically variable, such information needs to be distilled from long periods of observation. Unfortunately, wetland water level is rarely recorded, and where records are available, they are usually too short for reliable conclusions to be drawn.

Investigating the pattern of wetland water level variation usually relies on obtaining information about how the various components of the water budget vary through time. Although this information is sometimes difficult to obtain, when acquired, it is combined in a simple input-output model (adding inputs and subtracting outputs) to predict water level variation through time.

The problem of modelling the hydrology of a particular wetland can be simplified in the first instance by deciding which components of the general water budget (Figure 4a) need to be considered, since their importance varies with wetland type.

4.2.2 Main hydrologic types of wetland

Three main hydrologic types of wetland are identified in this document, distinguished by their dominant source of water input.

- Riverine floodplain wetland: floodplain depression fed by adjacent river (Figure 4b).
- Shallow basin wetland: depression fed directly by local catchment runoff (Figure 4c).
- Groundwater depression wetland: topographic depression in permeable soil which interacts significantly with groundwater (Figure 4d).

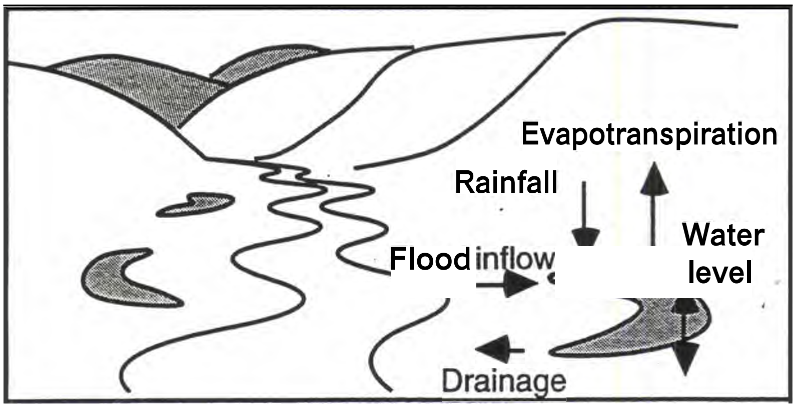


Figure 4b Main natural hydrologic components of riverine floodplain wetland

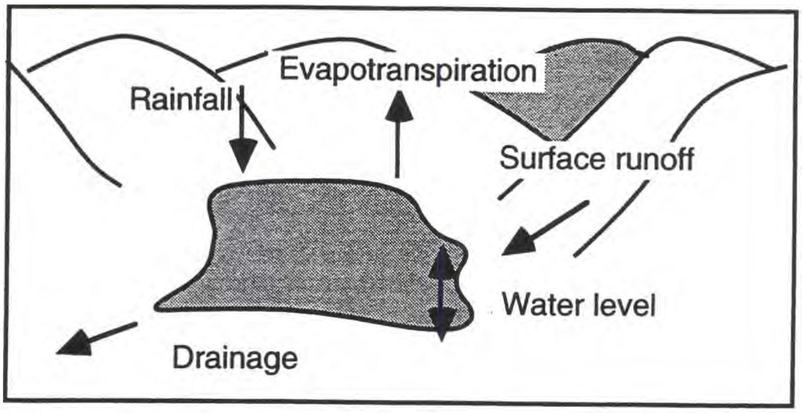


Figure 4c Main natural hydrologic components of shallow basin wetland

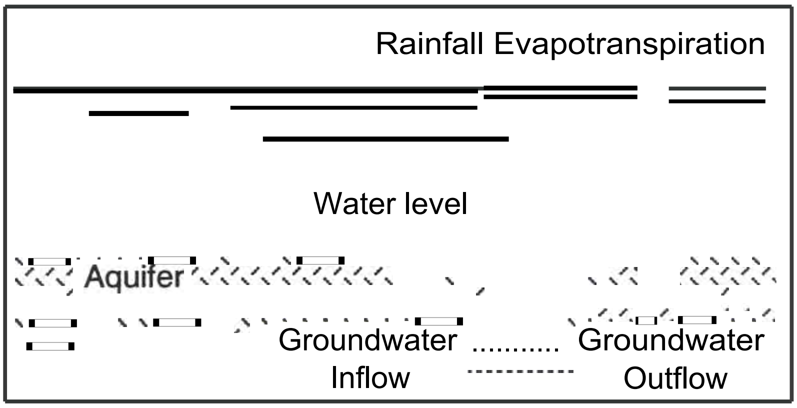


Figure 4d Main natural hydrologic components of groundwater depression wetland

Riverine wetlands

Riverine wetlands are common along the floodplains of major lowland rivers. They may be in the form of shallow swamps or marshes, or deeper billabongs and anabranches which flow only during floods. Such wetlands are often separated from the river by a natural levee, and usually are lined with a layer of clay which restricts groundwater exchange. Therefore, when the adjacent river is confined within its banks, the wetlands are thought to be hydrologically independent.

Macropores (usually animal burrows or tree roots), if present, may provide a hydraulic link through the clay to the surrounding soil.

Estuarine wetlands occur at the mouths of rivers, so their hydrology is complicated by marine and tidal influences. Water flows are complex and variable and a hydrodynamic modelling approach is appropriate. Modelling of estuarine systems is not specifically discussed in this document, but the techniques suggested for riverine wetlands can be used to model the river flow component.

Shallow basin wetlands

Shallow basin wetlands are predominantly fed directly by their upstream catchment. They can occur, for example, as coastal backwaters blocked by a dune system, or as ancestral channels or relict meanders located on the elevated floodplain of a prior stream. Such wetlands also occur in areas where geological processes have interrupted an established drainage system. An example is the way volcanic flows blanket or partially block stream systems and create new drainage lines, or cause basin infilling. Most established shallow basin wetlands have been partially infilled with sediment and, in the absence of macropores, a clay lining will restrict groundwater exchange.

Groundwater depression wetlands

Groundwater depression wetlands are topographic depressions in permeable soil which interact significantly with groundwater. They are situated such that the watertable periodically rises sufficiently to result in surface wetness. Low-lying coastal backwater wetlands in porous sandy material can have a significant groundwater component in their hydrologic budget. Groundwater wetlands can occur as isolated spring-fed wetlands, sometimes amidst shallow basin wetlands which are not controlled by the groundwater system. Surface flows generally also contribute to the hydrologic budget of groundwater depression wetlands.

4.3 DISTURBANCE OF WETLAND HYDROLOGY

4.3.1 Summary of factors that disturb wetland hydrology

Herbaceous vegetation is quick to respond to hydrologic changes (inundation frequency, duration, timing and water depth) while woody vegetation tends to reflect long-term trends in these parameters (Carter 1986). Wetland vegetation condition is thus a good indicator of changes in wetland hydrology. If a change in the floristic composition or community structure of a wetland has been observed and hydrological change is suspected, it may be possible to use information on key species requirements to infer whether the wetland has become generally drier or wetter. Van der Valk (1981) proposed a model of wetland vegetation succession in response to hydrologic changes and applied it to some North American and African examples.

Tables 4a, 4b and 4c list the main factors that alter wetland hydrology, indicate which components of the water budget are mainly affected, and denote whether the effect is positive (increase) or negative (decrease).

Table 4a Climatic factors that alter wetland hydrology naturally

	Surface flow		Precip.	Groundwater		Evap.
	in (Q_i)	out (Q_o)	(P)	in (G_i)	out (G_o)	(E)
Period of increased rainfall and runoff						
Period of decreased rainfall and runoff						

Table 4b Regional, or catchment factors that disturb wetland hydrology

	Surface flow		Precip.	Groundwater		Evap.
	in (Q_i)	out (Q_o)	(P)	in (G_i)	out (G_o)	(E)
Farm dams	-					
Irrigation scheme				+		
Large, regulated impoundment	-			+		
River channel sedimentation	+					
River channel incision	-					
River improvement	-					

Table 4c Local factors that disturb wetland hydrology

	Surface flow		Precip.	Groundwater		Evap.
	in (Q_i)	out (Q_o)	(P)	in (G_i)	out (G_o)	(E)
Erosion of nearby levee	+					
Construction of nearby artificial levee	-					
Diversion into wetland (roadside or irrigation)	+					
Blockage, or interception and diversion, of inflow source	-					
Water abstraction		+				
Excavation of outlet		+				
Blockage of outlet		-				
Groundwater pumping				-		
Soil compaction by stock				-	-	
Loss of fringing vegetation						+
Growth of fringing vegetation						+

4.3.2 Effects of disturbances on the wetland budget

Natural climatic variability

Precipitation naturally varies from year to year, but longer term climatic variations have also been observed. For example, there is evidence of a minor climatic shift in the 1940s in south-eastern Australia (Pittock 1975, 1983). The trend is the result of random variations and would be expected to occur with a probability of around 10% to 15% (Nathan et al. 1988). Figure 4e shows the residual mass rainfall, or cumulative deviation from the mean, for three locations in Victoria. Rainfall generally declined from the late 1800s till the late 1940s, after which it increased. Present rainfall is close to the long-term average. This trend can be ignored in most cases because the impact of climatic variation on wetland hydrology would be subtle in comparison with the effects of human disturbance. However, a concern for future management of wetlands is the possibility of increased flood frequency due to the greenhouse effect (Pittock et al. 1991).

The Australian climate is often characterised by periods of unusually high or low rainfall, and this can be reflected in runoff (Erskine and Warner 1988), and therefore wetland inundation. Unfortunately, the natural (pre-disturbance) period has usually been poorly recorded or unrecorded. This is because much of the human impact occurred before the widespread establishment of hydrologic monitoring, or because it was often the disturbance which prompted a monitoring program, such as the typical case of stream gauges being set up on a river after the construction of a dam.

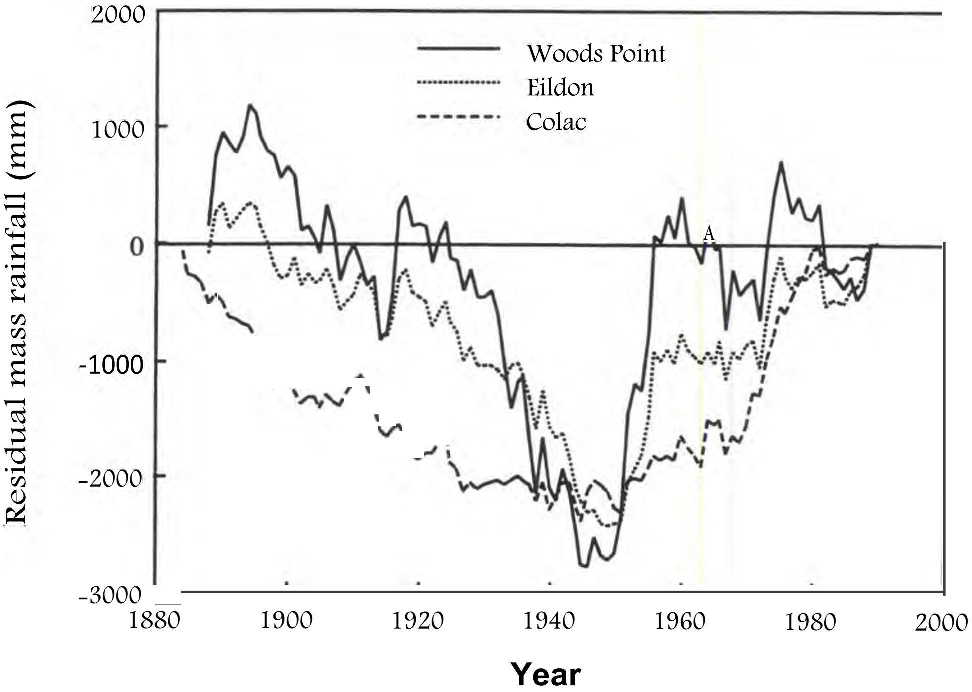


Figure **4e** Residual mass rainfall curves for Eildon, Woods Point (Goulbum River headwaters) and Colac.

Periods of record less than ten years long should be regarded with caution. For example, in the headwaters of the Goulburn River, which has a 100-year mean annual rainfall of 1478 mm recorded at Woods Point, a series of wet years occurred in the periods 1914-1924 (1581 mm average) and 1945-1955 (1734 mm average) (Figure 4e). The ends of these two phases happened to coincide with the construction of a major regulating dam in 1922, and substantial enlargement of the dam in 1955, respectively. So, in these cases, it is problematic to compare the pre-regulation phases, using a short record of potentially unrepresentative runoff data, with the post-regulation phases, which experienced lower than average and average rainfall conditions respectively.

Regional or catchment impacts

Catchment clearing can alter the runoff to rainfall ratio (Ring 1988) and may impact on the inputs to shallow basin wetlands. However, it has not been established that clearing changes the frequency and duration of flows large enough to inundate riverine wetlands (Ring 1988). Urbanisation creates areas with impermeable surfaces and increases the magnitude of floods for a given recurrence interval (Dewar and Robinson 1988). This implies an increase in the frequency of wetland inundation events. By intercepting a significant proportion of runoff, numerous small farm dams can reduce the runoff to rainfall ratio, but the effect is probably not significant for flood events (Srikanthan and Neil 1988). The catchment runoff to rainfall ratio can also decrease in response to bushfire, logging or afforestation (Schulze and George 1987, O'Shaughnessy and Jayasuriya 1991), but the impact of this disturbance on flood characteristics is unknown. One effect of large-scale irrigation schemes is a regionally elevated groundwater table, and associated salinisation of wetlands (Margules and Partners 1989, Lugg *et al.* 1989, Heron *et al.* 1991, Lugg *et al.* 1993).

Regulation of river flow by large impoundments can reduce average annual runoff, reduce seasonal flow variability, alter the timing of annual extremes, reduce flood frequency and magnitude, and impose unnatural pulses (Lillehammer and Saltveit 1984, Pats 1984, Klimas 1988). Changes in the characteristics of flows which are confined within the river channel do not directly alter the hydrology of riverine wetlands, and impoundments usually fail to mitigate very large floods. Rather, it is the flows which are sufficient to breach the banks that are of interest and it has been demonstrated that dams do alter the characteristics of these flows (Dexter *et al.* 1986, Bren 1987, Bren 1988a, 1988b). Also, the effect of a dam on wetland flooding reduces with distance downstream, as the stream acquires contributions from unregulated tributaries (Gippel and Finlayson 1993). Where major rivers are regulated to carry high flows throughout the summer irrigation season, low-lying wetlands immediately adjacent to the river may be affected by unseasonal inundation or groundwater inflow (Chesterfield 1986, Bren 1988b)

It is normal for river channel morphology to change through time (Brizga and Finlayson 1990). Channels naturally pass through sequences of incision and sedimentation, and the consequent changes in channel morphology can alter flooding characteristics. For example, an incised channel will have a larger capacity and therefore flood less frequently (Erskine *et al.* 1990).

Wetland hydrology can be indirectly affected by river improvement. Clearing, dredging and straightening rivers and streams, or constructing levees, will all increase the capacity of the channel to convey flood water (Taylor and Barclay 1985). This will theoretically reduce the frequency of flooding of associated wetlands (Gippel 1995). The pattern of flood flows on the floodplain can also be affected locally by bridges, roads and embankments. Floodplain clearing will reduce flood duration by increasing the velocity of flood waters flowing through wetlands (Kadlec 1990).

Local impacts

A riverine wetland may become more freely draining if the natural levee is eroded through the process of natural channel migration. Artificial levees constructed on the channel side of the wetland will reduce flooding frequency. Local, direct disturbance to wetland hydrology is usually in the form of drainage so that the land can be used for agriculture, or abstracting water for irrigation. However, water is sometimes diverted into wetlands from irrigation of nearby agricultural land, roadside table drains, or urban or industrial drainage.

Percolation is normal in wetlands with permeable soil. These soils are liable to compaction from grazing stock, which has the effect of increasing the duration of the wet period. Groundwater pumping has the effect of locally lowering the groundwater table, and therefore reducing the potential for groundwater input to wetlands.

Evapotranspiration rate is largely determined by climatic factors, and therefore varies from year to year. However, fringing vegetation also effects evapotranspiration rate by directly transpiring water from the wetland, or by shading the water surface from direct radiation and offering protection from wind.

4.4 TECHNIQUES OF INVESTIGATING WETLAND HYDROLOGY

The hydrology of a wetland is determined by first assessing the relative contributions of the various components of the water budget, and then ascertaining the timing of these contributions. Established hydrological techniques are available for this purpose, ranging from simple reconnaissance methods to sophisticated mathematical models. The choice of technique will be determined by the type of wetland, time available, and budget constraints. Generally, more sophisticated techniques should be employed for investigating the hydrology of high value wetlands, while rapid reconnaissance techniques are adequate for low value wetlands. At the simplest level, the wetland wetting and drying cycle can be deduced from observations made by local landholders or long-term wetland users.

4.4.1 Quantifying water budget inputs and outputs

Evapotranspiration

Evapotranspiration is the total evaporation from all water, soil, vegetation and other surfaces, and plant transpiration. Evapotranspiration rate depends on radiation, wind, humidity and temperature. While short-term fluctuations do occur, for the purpose of wetland modelling, only the longer term seasonal variations are important. For large, open wetlands, evaporation from the water surface is the dominant process. Most wetland vegetation transpires water from the underlying soil, rather than from surface water (Duever 1988a).

Evaporation from lakes can be measured by evaporation pan, or more accurately calculated by the energy budget or mass trans* methods (Winter 1981). The latter approaches require detailed climatic data that are not always available. The wind and thermal regimes of evaporation pans and lakes are usually markedly different (Winter 1981), and evaporation from open water wetlands is generally lower than that indicated by pans (Kadlec *et al.* 1988). Pan to lake coefficients are commonly used to predict lake evaporation from pan evaporation data, although some difficulties with this approach have been pointed out by Brutsaert and Yeh (1970). Hoy and Stephens (1979: 118) provide monthly pan to lake coefficients for a range of Australian lakes. These coefficients should not be regarded as definitive, since Hoy and Stephens (1979) found great variation in the coefficients between lakes. They reported a mean annual value of 0.7±0.1, based on results from many countries. Wetlands with prolific emergent vegetation may have evapotranspiration rates in excess of those indicated by pan evaporation (Duever 1988a).

The easiest way of obtaining average, seasonal evaporation (Class A Pan) data is by interpolation from maps in the *Climatic Atlas of Australia* (Bureau of Meteorology 1988). Long-term monthly mean values for evaporation (and other climatic variables) can be obtained for points of known geographic location using the ESOCLIM program (Hutchinson 1989), available from the Centre for Resource and Environmental Studies, Australian National University.

Through a simple modification to his complementary relationship areal evapotranspiration (CRAE) model, Morton (1983b) provided a method for determining lake evaporation from temperature, humidity and sunshine hours (or global radiation) observed in the nearby land environment. The software to calculate lake evaporation in this manner can be obtained from the National Hydrology Research Institute, Environment Canada. Alternatively, a computer program which performs the CRAE calculation, available from the Centre For Environmental Applied Hydrology, University of Melbourne (Nathan and McMahon 1991), could be modified to calculate lake evaporation.

Rainfall

Daily, monthly and yearly rainfall data are available from the Bureau of Meteorology on microfiche, computer tape, floppy disc or compact disc. For a simple model, long-term monthly average rainfall will suffice. A more detailed wetland water level model should make use of the daily record.

Generally the closest rainfall gauge to the wetland should be used. However, closeness of the gauge should be traded off against the length of record available, and whether the gauge is situated in a place which is climatically similar. A short record from a nearby station can be extended if there is a longer record available from a more distant station. First establish a relationship between rainfall at the two stations over the period when records are available for both (using a regression technique), then use this relationship to predict rainfall at the nearby station for earlier or missing years (Gippel 1993). The rainfall at a point of interest can also be synthesised from the records of a network of surrounding gauges using various interpolation techniques (Institution of Engineers, Australia 1987: 15-40, Hutchinson 1989).

Groundwater

Wetland models often assume that groundwater exchange is either insignificant or in balance on an annual basis, and it is therefore ignored (Duever 1988). Other studies demonstrate the potential complexity of groundwater exchange near wetlands (Anderson and Munter 1981, Townley *et al.* 1991), and cases of significant groundwater exchange have been reported. For example, Brown *et al.* (1988) found that groundwater constituted 45% of the inflows to a Wisconsin wetland. Gutteridge, Haskins and Davey Pty Ltd (1980) proposed that lakes in the western region of Victoria are probably recharged by groundwater in summer and discharge to groundwater in winter, but that there is no net gain or loss over a year. However, even if this is the case, groundwater exchange must be included in a model if seasonal water level fluctuations are to be explained (Gippel 1993).

The process of groundwater exchange between wetlands and the surrounding soil is probably the least understood aspect of wetland hydrology. Duever (1988a) argued against significant groundwater exchange because the level of most wetlands coincides with the regional watertable, and because wetlands are characteristically underlain by a relatively impermeable clay or organic layer. However, even clay is not impervious, and minimum seepage rates of 5 mm/day are reported for irrigation canal linings (Deacon 1984, Wachyan and Rushton 1987). It is also conceivable that the clay/organic layer could be bypassed via preferred pathways (animal burrows or tree roots).

Many rivers in Victoria build natural levees and are elevated slightly above the general floodplain level (Brizga and Finlayson 1990). Associated floodplain wetlands are therefore located at a similar or slightly lower elevation than the adjacent river. This morphology limits the head available to drive groundwater exchange. Only in cases where there is a permeable link from the wetland to the river should wetland water level be highly responsive to river level. The link could be a permeable sand lens, or a network of preferred pathways.

Groundwater depression wetlands are by definition strongly influenced by groundwater level, and piezometer data, if available, will provide a good indication of wetland water level fluctuations. In Victoria, groundwater levels are monitored at numerous locations, but they are usually restricted to areas where rising watertables from irrigation is an identified problem [see Rural Water Commission (1990) for list of gauges].

For riverine and shallow basin wetland types, the importance of groundwater exchange is variable. Piezometers can be established near the wetland and groundwater level changes compared with changes in the wetland water level (LaBaugh 1986, Hollands 1987). The volume of inflow and outflow can be estimated using a groundwater flow model (Stark and Brown 1987, Gippel 1993). The likelihood of percolation can be investigated by extracting a core from the bed of the wetland and measuring its hydraulic conductivity. There is a danger in performing this test in the field when the wetland is dry because any cracks (which may close upon saturation) will act as preferred pathways and falsely indicate permeability. A better alternative is to use an in situ seepage meter (Lee 1977, White and Denmead 1989). A simple technique for observing the depth of the watertable is to monitor the oxidation of steel rods placed vertically in the soil profile. However, the technique is unreliable in areas where the groundwater level fluctuates widely (Bridgham *et al.* 1991).

For riverine wetlands, a simple monitoring approach is to compare water levels in wetlands with water levels in the adjacent river. If water levels fluctuate with changing river levels (when flow is confined within the banks) then a groundwater connection is indicated. If no groundwater connection exists, then wetland water levels will reflect the balance of rainfall inputs and evapotranspirative losses.

Duever (1988a) felt that the effort required in measuring groundwater exchange would be better spent on measuring other processes that account for much larger and variable fluxes. However, Winter (1981) found that errors of 5-30% are typically incurred in measurement and estimation of each of the components of a lake water budget. Comparison of several lake water balances in which the residual consisted only of measurement errors, revealed that such a residual, if interpreted as groundwater exchange, can differ from independent estimates of the groundwater component by more than 100%.

Surface flows

Riverine floodplain wetland—gauged catchment

The surface flow inputs to a riverine floodplain wetland are mostly from flood events that top the river banks. There may also be some drainage from surrounding valley slopes, or irrigation outfall. Little is known about the role of the floodplain as a local catchment area for riverine wetlands. In summer, the infiltration capacity of undisturbed floodplain soils would normally be high enough to absorb all but exceptional rainfall intensities, and the wetland catchment area is the wetland surface itself. However, it is possible that during winter, when soil moisture is high, rainfall events will result in overland flow over wide areas of the floodplain. Overland flow may also occur after summer rainfall events on irrigated floodplains where soil moisture is artificially high, or where grazing has compacted soils.

River regulation by a large impoundment is a common problem for riverine wetlands (Klima s 1988, Gippel and Finlayson 1993). Rivers regulated for irrigation requirements tend to have an inverted seasonal flow pattern as capacity flows are released in summer and winter and spring runoff is collected to fill the impoundment. However, this seasonal flow inversion does not greatly impact on surface inflows to wetlands. The exception is low lying wetlands which are adjacent to low points on the bank which tend to be inundated by unseasonal summer flows. To fill, most wetlands require a substantial flood flow which overtops the banks.

The temporal pattern of surface inflows to low lying wetlands is given by the record of river flows at a nearby gauge, combined with knowledge of the threshold river height (or discharge) at which the flow tops the banks sufficient to result in inundation. The frequency of inundation of higher elevation wetlands can be determined by using a higher threshold discharge.

Determining threshold wetland flooding height

Information on river gauge heights at which particular wetlands are filled by surface flows can be sought from River Management Boards and River Improvement Trusts who frequently have acquired this information in relation to their activities in flood mitigation. State water authorities are a good source of information on channel capacity, especially for rivers used for the conveyance of irrigation water or having a history of river management problems associated with flooding. Local landholders are frequently able to provide quite detailed information about the minimum gauge height associated with flooding on their land. The Bureau of Meteorology is a convenient source of information about the relation between gauge height and flooding at particular gauging stations (Bureau of Meteorology 1985). The Bureau maintains such records for use in the State Flood Warning Scheme. Minor flooding is defined as causing inconvenience such as closing minor roads and submerging low level bridges, and this level is convenient as an index of the minimum discharge at which wetland inundation occurs (Gippel and Finlayson 1993, Nathan 1992). The stated level of accuracy of the threshold flooding gauge heights of ±0.5 m is probably conservative. In reality, the accuracy would vary with absolute river height. The Bureau advises that for most rivers, the threshold flood height should be well within the stated level of accuracy.

For a regional study, a single threshold flooding level can be assigned to represent the wetland area in the vicinity of a gauging station. The methods of acquiring this information are inexpensive, but unreliable in the sense that local information may not be available for specific wetland areas of interest. Given more detailed knowledge of flood flow paths on the floodplain, the same analyses could be repeated for other thresholds associated with particular individual wetlands or groups of wetlands. In this case, field surveys of floodplain microtopography are necessary. Where the wetlands of interest are close to gauging sites, surveyed levels can be related directly to gauge heights.

Where the wetlands of interest are distant from a gauge, it may be possible to use backwater calculation models such as HEC-2 (United States Army Corps of Engineers 1990) to relate the gauge level to the local wetland inundation level. This technique has large data requirements and would be feasible only for a detailed investigation (Gutteridge, Haskins and Davey Pty Ltd 1991a).

Hydraulic modelling is recommended for large wetlands, since some floods, which are above the threshold but of short duration, will only partially fill the wetland. In cases where large riverine wetlands are interconnected, a flow routing model should be applied. For example, Gutteridge, Haskins and Davey Pty Ltd (1991a) modelled the Latrobe River wetlands using HEC5Q (Wong and Wellington 1990), and the more user friendly MIKE11 was used by Bewsher et al. (1991) to model the Barmah—Millewa forests on the River Murray.

In some large wetland systems with complex hydraulic interconnections it may not be feasible to survey the topography at the detail required for a hydraulic model. It is difficult to model the roughness characteristics of complex vegetation patterns.

Also, there may be many inlets to the wetland system that spill at different river heights. Difficult problems such as this are perhaps best modelled by observing actual flood events. This could be done by tracking the extent of wetland inundation over a flood event (using a sequence of remotely sensed images, or on ground mapping) and then modelling the pattern of inundation as a function of river height (or discharge). A Geographic Information System (GIS) would be ideal as a platform for the modelling. Interpolation of the spatial pattern of flooding between images would enable wetland inundation to be mapped as a continuous function of river height. Ground surveys of elevation would enable estimation of the volumes of water involved.

Obtaining river flow records

River discharge records are available from government water authorities, who also should be consulted regarding the regulation history of the river. This consists of a list of the dates on which particular forms of flow regulation began and ended. A national list of river gauging records has been published by the Australian Water Resources Council (1982). In Victoria, monthly data are available from Rural Water Commission (1990). This publication also provides information on the location of gauges and the length and quality of record. In New South Wales, the Department of Water Resources has recently made Victoria's river flow records available in a compact disk package (Department of Water Resources 1990). Having selected an appropriate gauge, daily flows must be obtained directly from the relevant gauging agency. These records are commonly in discharge units of ML/d. Since flood warning information (and other local information) is invariably expressed as gauge height in metres, it is necessary to also acquire the rating tables for the selected gauging stations so that the flooding threshold river heights can be expressed as a discharge value.

Flow records shorter than approximately ten years should be regarded with caution, especially for highly variable streams. However, given the availability of suitable rainfall records, the flow record can be extended by rainfall-runoff modelling (Haan *et al.* 1982).

Riverine floodplain wetland—poorly gauged river and catchment

Runoff estimation techniques for ungauged catchments are not usually applicable to the problem of riverine floodplain wetland hydrology because their use is generally restricted to small catchments, whereas significant floodplain wetlands mostly occur on lowland rivers which have a substantial catchment area. It is not possible to generate a reliable synthetic daily flow record for a river draining a large heterogeneous catchment without some flow data being available for calibration.

Determining threshold wetland flooding height

The discharge at which a river overtops its banks (and therefore inundates low-lying wetlands) can be estimated for ungauged rivers by using a uniform flow resistance formula (Institution of Engineers, Australia 1987: 59). The most popular method is the Manning Formula:

$$Q = \frac{AR^{2/3}S^{1/2}}{n}$$

where:

Q = discharge for the defined cross-section (m^3/s)
A = channel cross-sectional area (m^2)
R = hydraulic radius (m)
S = bankfull water surface slope (m/m)
n = roughness coefficient

The hydraulic radius (R) is the cross-sectional area divided by the wetted perimeter. In wide, shallow channels, R is approximately equal to average depth. The roughness coefficient (n) of the channel can be estimated from tables in Chow (1959), or by comparison with photographs of typical channels of known roughness in Barnes (1967) or Hicks and Mason (1991). Bankfull water surface slope is difficult to measure directly. Indirect measurements of S are slope of the floodplain surface or flood debris lines. The channel cross-sectional area is determined by field survey.

Obtaining river flow records

In cases where there is no river gauge in the vicinity of the wetland of interest, it is necessary to develop a flow routing model which will, on the basis of flow data available for other parts of the catchment, generate a synthetic flow record for the river adjacent to the wetland (eg Gutteridge, Haskins and Davey Pty Ltd 1991a). A hydraulic flow routing model (Monthly Simulation Model, MSM) has been developed by the Murray—Darling Basin Commission to generate synthetic pre-regulation flow records for the Murray River. This model has been used to model natural flooding regimes for several wetlands in the Murray River basin (Dexter *et al.* 1986, Beovich and Lloyd 1993a, 1993b, Beovich 1994). The results of these studies are summarised in Atkins (1993). In Victoria, similar models have been developed, or are in the process of being developed, for all large regulated rivers.

If only part of the catchment is gauged, a rainfall-runoff model can be calibrated for gauged sub-catchments. The model can then be applied to the ungauged sub-catchments (using parameters applicable to the catchment condition) to produce synthetic flow records. The sub-catchment flows are then linked using a flow routing model which estimates a flow record for the river in the vicinity of the wetland of interest.

In cases where the river in the vicinity of the wetland is ungauged, and a flow modelling approach is not warranted, flow records from an upstream gauge may be used as a guide to the frequency of inundation of the wetland.

In the absence of flow data, an approximate estimate of the frequency of wetland inundation events is given by the average recurrence interval of bankfull flow. Analysis of the partial flood series of numerous rivers suggests that a bankfull flood occurs on average once per year (Institution of Engineers, Australia 1987: 231). This is similar to the frequency of independent floods that, prior to river regulation, inundated wetlands on the lower Goulburn River (Gippel and Finlayson 1993) and lower Thomson River (Gippel and Stewardson 1995). The actual frequency of flooding for a specific wetland depends very much on its elevation and the nature of its links with the river system. Atkins (1993) summarised results of studies of a range of Murray River wetland systems. The percentage of years in the record experiencing winter-spring wetland inundation events prior to regulation ranged from 70% to 97%.

Shallow basin wetland

Riverine floodplain wetlands are inundated only when storm events are large enough to cause the river to top its banks. In contrast, shallow basin wetlands receive surface inputs from every storm event that causes runoff, and baseflow may be a constant source of surface water input.

For most shallow basin wetlands, the inflow is ungauged. Surface inflow is the most important component of the water budget of most wetlands, so it is necessary to estimate its volume and regime. A rough estimate of the annual or storm event runoff volume from a catchment can be made using the runoff coefficient method. A more sophisticated approach is to use a rainfall-runoff model to generate a detailed flow record.

Runoff coefficient method of flow estimation

The runoff coefficient method is popular in Australia for estimating water yield from ungauged catchments. The method simply multiplies the rainfall (over any time period) by a runoff coefficient to give runoff per unit area.

Annual runoff coefficients tend to vary consistently with catchment size within a defined hydrological region, but the form of the variation may be different from region to region (Cordery et *al.* 1980, Pilgrim 1983). Runoff coefficients can be derived on a monthly, daily or storm event basis, but the relationship generally becomes weaker as the time interval is shortened. The main problem is that the volume of water stored in the catchment as soil moisture varies as a function of the temporal pattern of rainfall. Storm event or short time interval runoff coefficient models can be improved by including more variables in the relationship. For example, soil moisture status can be represented by an index which combines the time elapsed since the last rainfall event with the amount of rain received.

The procedure for deriving the runoff coefficient for an ungauged catchment is to first calculate actual coefficients for nearby gauged catchments with similar physiographic characteristics. These coefficients are graphed against catchment area and then the coefficient for the ungauged catchment is simply read off according to its measured catchment area. Since the runoff coefficient method is widely used, water authorities may be able to provide advice on selection of an appropriate coefficient.

Nelson (1985: 9) provides a table of coefficients for estimating runoff from small catchments. The value of the coefficient depends on rainfall, evaporation, soil type and vegetation cover. The coefficient expresses runoff as a percentage of rainfall and is used in the equation:

$Q = 100\ ARY$

where

$=$ annual runoff in litres

$A =$ catchment area in hectares

$R =$ average annual rainfall in millimetres

$Y =$ runoff coefficient (°/0)

Nelson (1985: 10) provides an example of the use of the runoff coefficient method:

Example:
A small catchment of 100 ha is forested and the soil is sandy clay. It receives an average annual rainfall of 750 mm and has an annual evaporation of 1000 mm. What would the estimated annual yield be?

$A =$ 100 ha

$R =$ 750 mm

$Y =$ 7.5% (reliability of 8 years in 10) (from table)

Therefore, runoff $= 100 \times 100 \times 750 \times 7.5$

56 250 000 L

56.3 ML

Hudson (1981: 114-116) also provides tables of empirical runoff coefficients for different topographic, land use and soil classes, but they were derived to suit USA and African conditions and may have limited application in Australia.

If a storm event runoff coefficient model is used then it is necessary to make an estimate of the contribution of baseflow throughout the year. This is perhaps best approached by actually measuring baseflow discharge into the wetland at representative times of the year.

An approximation of annual catchment runoff can be obtained from maps in the Climatic Atlas of Australia (Bureau of Meteorology 1988).

Rainfall-runoff model method of flow estimation

Rainfall-runoff models are mathematical formulations that attempt to simulate hydrological runoff processes on the basis of rainfall and evapotranspiration data and various catchment parameters (Haan et al. 1982). They range from simple polynomial equations to complex conceptual daily flow models. Chiew et *al.* (1993) found that the simple models provide adequate estimates of annual and monthly yields, but recommended the use of a complex model for simulating daily flows. Hydrological modelling is not a straightforward procedure (Bevan and Binley 1992; Grayson et al. 1992), and specialist expertise would be required in most cases.

A model that has been developed for south-eastern Australia, the SFB model, is available as an interactive computer model from the Centre For Environmental Applied Hydrology, University of Melbourne (Nathan and McMahon 1991). The model is simple, but difficulties arise in parameter optimisation and calibration. It uses daily rainfall and evapotranspiration data combined with three catchment parameters: S, the surface storage capacity; F, the daily infiltration capacity controlling percolation from the surface to the groundwater store; and B, a baseflow factor that determines the portion of the daily depletion of groundwater that appears as baseflow runoff. The output is a monthly or daily flow record. Application of the SFB model is illustrated in Nathan and McMahon (1990). Advice on data sources and parameter selection are given in Nathan and McMahon (1991).

Areal evapotranspiration is an important component of the rainfall/runoff process. Sometimes evaporation data may be available for a nearby weather station. However, pan evaporation data are notoriously unreliable and do not necessarily reflect actual evapotranspiration. The recommended alternative is Morton's CRAE method (Morton 1983a). A computer program which performs this calculation is Nathan and McMahon (1991) already mentioned above.

Assessing representativeness of records

It is important that the records used to characterise the current or natural water regime of a wetland are representative of the actual period. This applies especially to Australian streams, which have highly variable flows by world standards (Finlayson and McMahon 1988). For example, in investigating the possibility that river regulation from a large impoundment has reduced wetland flooding frequency, it would be wise to check that other disturbances did not coincide with regulation, and that the pre- and post-regulation phases were not unusually wet or dry.

A simple technique is to use long-term rainfall records to check that the periods for which records are available did not coincide with unusually wet or dry spells. A more sophisticated technique is to examine the flow record (partitioned according to the pre- and post-disturbance periods) of a nearby control gauging station which has not been affected by the disturbance.

Trends in rainfall records

The existence of periods where the natural hydrologic regime deviated from average conditions can sometimes be observed from plots of cumulative annual rainfall. Steepening of the curve indicates a period of increased rainfall, and flattening of the curve indicates a period of lower than average rainfall.

Another graphical method of examining rainfall records is to construct a residual mass rainfall curve. The annual rainfall for each year is subtracted from the long-term mean. The cumulative deviations are then plotted (Figure 5). A negative slope indicates lower than average rainfall conditions and a positive slope indicates higher than average conditions. The same procedure could be followed using monthly or annual data.

Trends in flow records

The representativeness of river flow records can be assessed by selecting a nearby hydrologically undisturbed river and partitioning its record according to the pre- and post-regulation phases identified for the wetland of interest. A double mass plot of annual or monthly flows will reveal if the flow disturbance was significant compared with natural variations. In the case of floodplain wetlands, it is more appropriate to compare the flooding regimes of the regulated and unregulated river.

The simplest approach to flood analysis is to compare annual flood series curves. These curves indicate the annual exceedance probability, or average recurrence interval, of floods of a given magnitude (Institution of Engineers, Australia 1987: 197-236, Gordon et *al.* 1992: 354) (Appendix 4a). In practice, annual series curves for different periods of a natural hydrologic record do vary because of natural variations in hydrologic regime over the time scales covered by the gauging records. Gippel et al. (1991) split the flow records of ten unregulated Victorian streams into two selected periods and found natural differences of -12% to 18% in the magnitude of the discharge corresponding to the flood with an average recurrence interval of two years. The difference between the two periods was not consistent among the streams. Similarly, when the average recurrence interval (using the annual series) of the wetland flooding threshold discharge was compared for the two selected periods, inconsistent differences of up to ±0.2 years were revealed. Thus, average recurrence intervals calculated for the natural pre-disturbance period should be interpreted within this level of accuracy, and for a change to be associated with disturbance it should exceed this.

If flow records are found to be unrepresentative, then this must be borne in mind when interpreting the results of hydrological analysis. The alternative is to generate a synthetic natural flow record. Given adequate calibration data, monthly pow models are probably sufficiently accurate. However daily flow data are often required and daily models are less reliable, particularly for flood flows (Nathan 1992). This is unfortunate because floods are of major interest with respect to wetland inundation. The limited accuracy of a modelled record must be balanced against the unrepresentativeness of the gauged record.

4.4.2 Determining the water level regime

The wetland water level regime, or time series of DS in the water budget equation, is calculated by balancing the components of the water budget over the desired time interval. Annual data are adequate for a deep, permanent wetland, where drying is of no interest, and the objective is to detect long-term losses or gains. However, for most purposes, seasonal, monthly or daily records are preferred. Simple indices for characterising the water level time series are: frequency of occurrence of wet periods and dry periods; mean, median and range of duration of wet periods and dry periods; and seasonality of wet periods and dry periods.

There are five basic steps in determining the water level regime of a wetland.

1 Collect or model data on the components of the water budget.
2 If appropriate, date the important periods of hydrologic disturbance. Then partition actual or modelled hydrologic records according to these identified phases. Usually, the phases will be pre-disturbance (natural) and post-disturbance (current).
3 Assess the representativeness of the records. If they are unrepresentative, this should be kept in mind when interpreting the results.

4 Survey the topography of the wetland. A volume-depth and/or volume-area relationship will enable calculation of inundation duration and frequency at a range of elevations. The timing and duration of dry periods can be obtained by simply measuring the maximum depth of the wetland.

5 Establish the water level regime for the identified *natural* and *current* phases

Riverine floodplain wetland

Simple techniques for ungauged or poorly gauged catchments

Bankfull flood frequency method

1 Assume that there is an annual wetland inundation event.

2 Consult average rainfall records and select the month of highest rainfall as the flood month.

3 Balance monthly rainfall and evaporation to determine if, and in what month, the wetland dries out. The wetland will probably dry out if the difference between annual rainfall and evaporation is greater than the wetland depth.

Simple method using upstream gauging data

1 Estimate the inundation threshold discharge of the river *(Qx)* in the vicinity of the wetland of interest located at X, using the Manning equation.

2 Construct an annual series curve (Appendix 4a) for the upstream gauging station (Y).

3 Measure the catchment area at points X and *Y (Ax* and Ay respectively) from a topographic map.

4 Calculate Qy using the relationship of Alexander (1971):

- $Q_y = Q_x\left(\frac{A_y}{A_x}\right)^{0.7}$

5 The frequency of wetland inundation floods is equivalent to the probability of exceedance of the flood corresponding to Qy. For example, an exceedance probability of 80% means that wetland inundation floods will occur in 80 years out of 100.

6 Consult discharge records from station Y and select the month with the highest flood frequency as the flood month.

7 Balance monthly rainfall and evaporation to determine if, and in what month, the wetland dries out.

Techniques for gauged catchments

For large wetland systems consider development of a hydrodynamic model, or actually map the extent of inundation during flood events and relate it to river heights. The techniques below are appropriate for smaller systems, or individual wetlands, where a relatively simple relationship between river height and wetland inundation can be identified.

Approximation of inundation frequency only

1. Construct an annual series curve (Appendix 4a) for the nearby gauging station (Figure 4f).

2. The frequency of wetland inundation floods is equivalent to the probability of exceedance corresponding to the identified threshold inundation discharge.

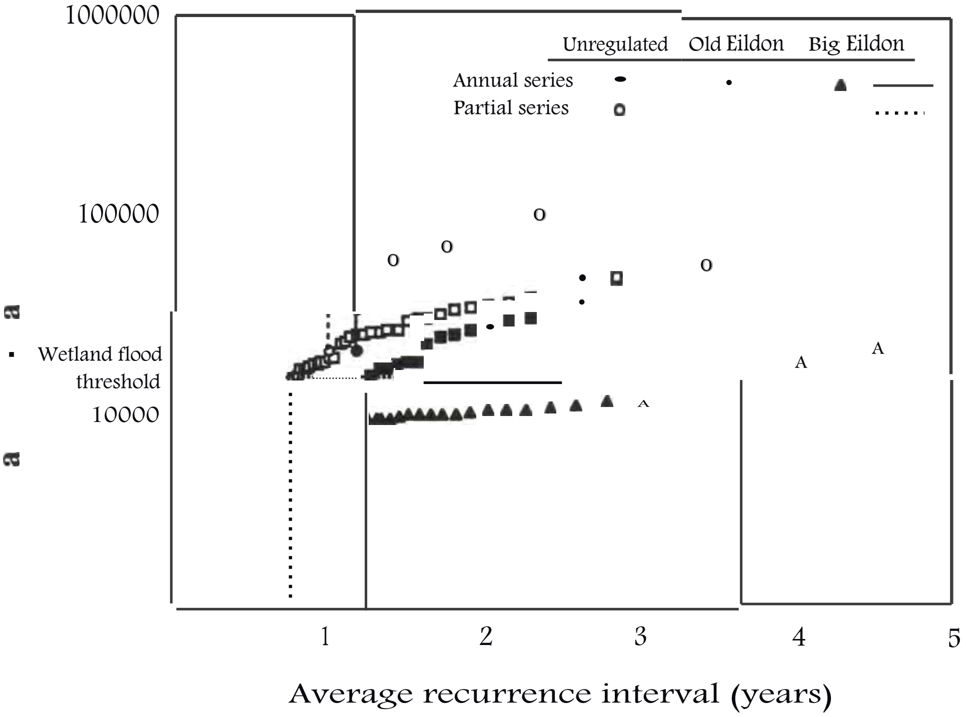


Figure 4f Annual flood and partial duration series plots for three regulation phases at Eildon, just below a dam on the Goulbum River, Victoria

For example, an exceedance probability of 80% means that wetland inundation floods will occur in 80 years out of 100.

The Old Eildon dam was constructed in 1922 and enlarged to Big Eildon in 1955. The frequency of wetland inundation floods is equivalent to the average recurrence interval of the flow corresponding to the threshold inundation discharge, identified by the minor flood warning level. The partial series is preferable, but the annual series is rapidly calculated. Note the marked decreased flooding frequency after Big Eildon. [Based on data in Gippel et al. (1991)].

Detailed analysis of daily hydrologic records

1. Count the number of independent, wetland flood events which occurred over the period of record (equivalent to a partial flood series, see Figure 4f and Appendix 4a), divide by the years of record, and multiply by 100 to give frequency of wetland inundations per 100 years. Some above threshold flows may be part of a series of peaks which together comprise a single inundation event, and are therefore not truly independent. Independent peaks can be arbitrarily defined as being separated from the next peak by 30 flood-free days (Appendix 4a).
2. Count the number of years in the record that experienced at least one wetland flood event, divide by the years of record, and multiply by 100 to give percentage of years experiencing wetland inundation.
3. Count the frequency of inundation events for each month and express as a percentage of the total events on record. Graph as a frequency histogram of

wetland floods per month (express the frequency as a percent of total events). This indicates which months are suitable for inundation (Figure 4g).

4 Calculate the mean, median and range of duration of wetland floods (number of days water level is above the threshold). This indicates the duration of active wetland flooding by river flows.

5 Calculation of average flood volume can be used to estimate the percentage of mean annual runoff used for wetland flooding, which may be required for negotiation of a water allocation.

6 Balance rainfall and evapotranspiration records (consider, groundwater exchange, abstraction, drainage and control by structures if important) to determine the time series of the drying rate of the wetland. This can be calculated on a monthly or seasonal basis using average climatic data.

7 Combine the wetland flood time series and the drying rate time series to give the time series of wetland water depth and/or area.

8 Calculate the mean, median and range of water depth for each month.

9 Calculate the mean, median and range of duration of wetland wet periods.

10 Count the number of times the wetland dries down, divide by the years of record, and multiply by 100 to give frequency of wetland dry periods per 100 years. The wetland dries down if the next wetland flood does not occur before the time to dry (which depends on the season of the flood) elapses.

11 Calculate the percentage of time that the wetland is dry.

12 Calculate the mean, median and range of duration of wetland dry periods (number of days wetland is dry).

13 Summarise the wetland hydrologic regime by constructing a frequency histogram of months when the wetland was wet and another for months when the wetland was dry (Figure 4h).

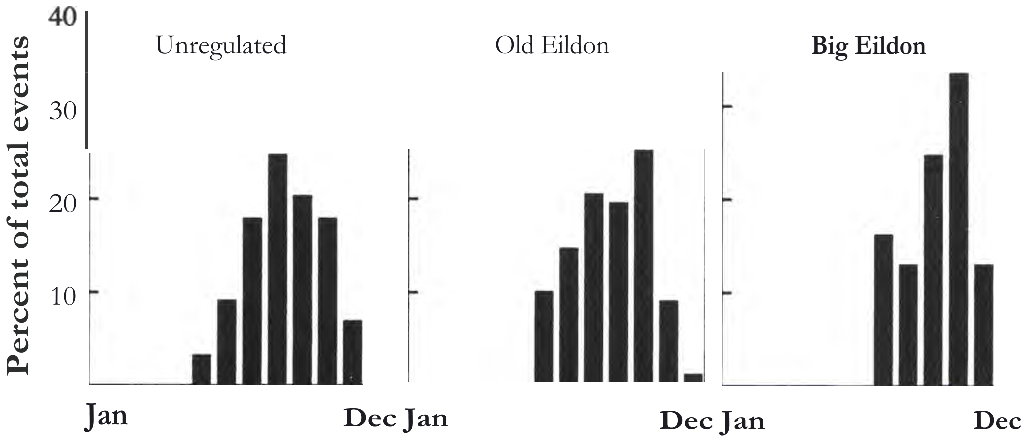


Figure 4g Seasonal distribution of independent wetland inundation events at Eildon, Victoria, through three regulation phases. The impact of regulation is small, except for elimination of floods in winter when the dam is filling. Based on data in Gippel *et al.* (1991).

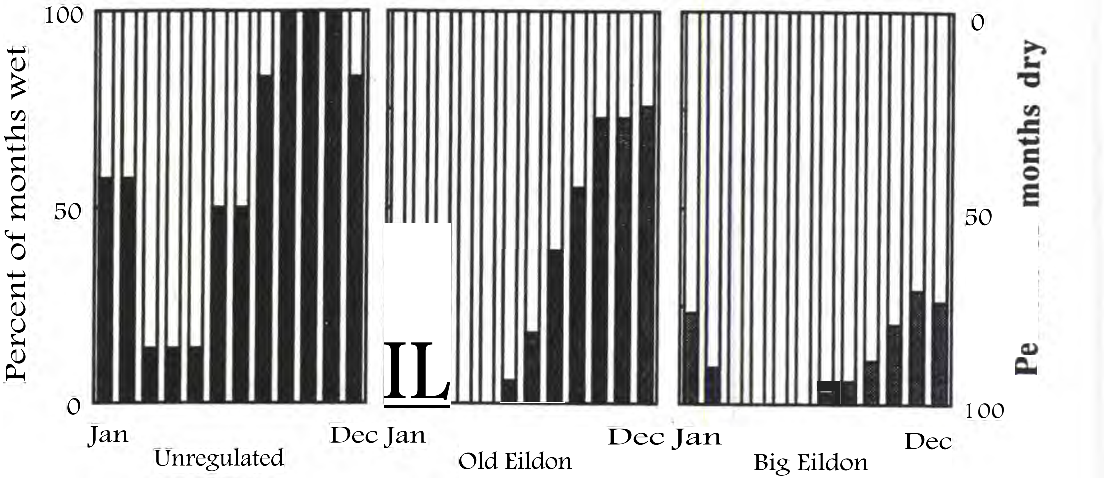


Figure 4h Summary of modelled changes to the hydrological regime of a hypothetical 0.5 m deep wetland near Eildon, Victoria, through three flow phases. The impact of regulation is marked, with the wetland changing in character from being essentially wet to essentially dry. Based on data in Gippel *et al.* (1991).

Shallow basin wetland

Simple annual water budget method

1. Estimate the volume of water that the wetland will hold by multiplying surface area by average depth.
2. Calculate the annual runoff for all years over the period of interest using an appropriate runoff coefficient.
3. Balance the average annual rainfall, evapotranspiration and runoff and compare with wetland volume (consider groundwater exchange, abstraction, drainage and control by structures if important). If there is a large deficiency (ie the residual is large and negative) then the wetland will probably dry out frequently. Smaller deficiency values indicate less frequent drying, while a large excess indicates infrequent drying or permanent wetness.
4. The water level time series can be approximated by continuously balancing the annual water budget for the period of interest (ie carry over any excess onto the next year). The water level regime can be expressed as years when the wetland filled or partially filled (depending on annual runoff and antecedent water level), and whether or not it probably dried out.

Technique for gauged or modelled catchments

1. Balance rainfall and evapotranspiration records (consider groundwater exchange, abstraction, drainage and control by structures if important) to

determine the time series of the drying rate of the wetland. This can be calculated on a monthly or seasonal basis using average climatic data.

2 Combine the wetland flood time series and the drying rate time series to give the time series of wetland water depth and/or area (Figure. 4i).

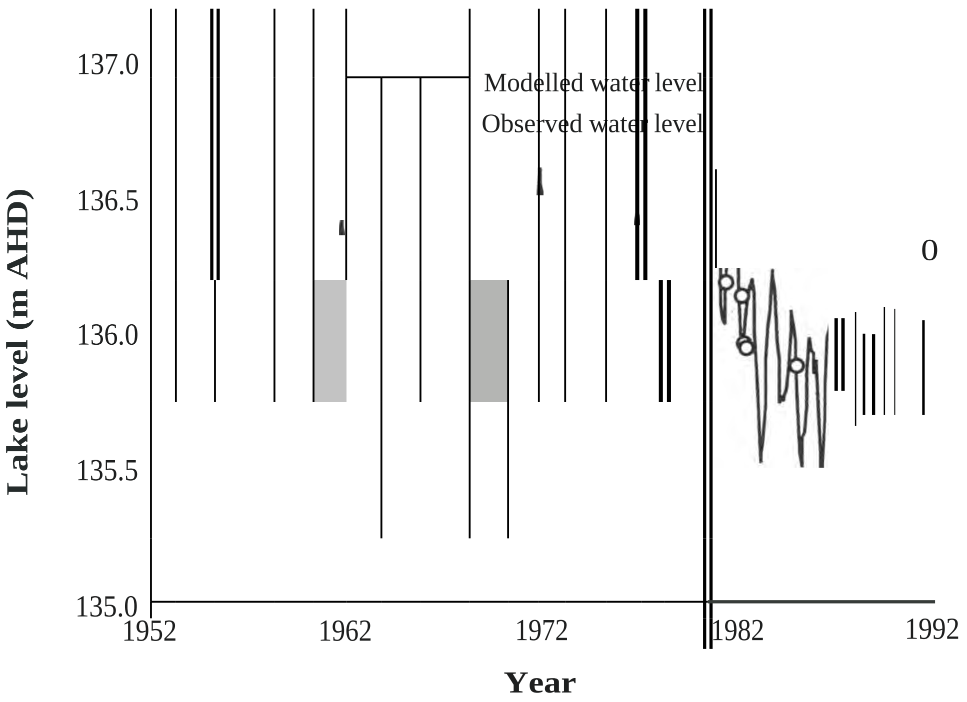


Figure 4i Monthly modelled time series of the water level in Lake Pirron Yallock, Victoria, Australia.

3 Calculate the mean, median and range of water depth for each month.

4 Count the number of times the wetland dries down, divide by the years of record, and multiply by 100 to give frequency of wetland dry periods per 100 years. The wetland dries down if the next wetland flood does not occur before the time to dry (which depends on the season of the flood) elapses.

5 Calculate the mean, median and range of duration of wetland dry periods (number of days wetland is dry).

6 Summarise the wetland hydrologic regime by constructing a frequency histogram of months when the wetland was wet and another for months when the wetland was dry.

Modelled data were within 0.1 m of measured levels. The lake has floating peat islands that are grounded at 136.1 m. They were incorrectly thought to have floated uninterrupted until 1982 (in fact they were grounded for 30% of the time). The water level fell suddenly after a drought in 1982, remained low, and never overflowed, although this change was incorrectly attributed to abstraction of water (in fact it was due to changed rainfall conditions). [Based on data in Gippel (1993)].

Groundwater depression wetland

1. Observe the seasonal variation in depth of the watertable. The wetland will become wet when the watertable comes close enough for vertical transfer of water by capillary action.
2. Proceed using the techniques described for shallow basin wetlands.

4.5 RESTORATION AND MANIPULATION OF WETLAND HYDROLOGY

4.5.1 Restoration of a natural hydrologic regime

There are numerous physical, legal, social and political barriers to restoration of the natural hydrologic regime of a wetland, and realistically, this will rarely be possible. However, characterisation of the natural hydrologic regime does provide a rational basis for negotiation, planning and management of a compromise.

Regional approach

Catchment disturbances and large impoundments have a regional effect on associated wetlands. For example, Gippel and Finlayson (1993) found that the effects of Lake Eildon on wetlands of the Goulburn River valley persisted for a distance of almost 200 km downstream of the dam. Little can be done in the short term to reverse the effects of catchment disturbance. However, there is scope for managing large impoundments to satisfy wetland water requirements. In many cases in Australia, irrigation and wetlands have quite different water requirements. Irrigation requires water continuously throughout the summer months, while wetlands require periodic filling, often in late winter or spring. Irrigation demands a reliable, annual supply of water, while it is natural for wetlands to experience a variable water regime. Irrigation and wetland management could be compatible if a minimum wetland allocation was granted priority above over-year storage during wet years. Unlike irrigation planning, which involves an annual cycle, management of wetland water requirements should be considered over a longer time scale (5-10 years).

Special releases from impoundments for wetland inundation could be made in wet years, when the wetlands would probably have naturally flooded, and when irrigation demands are low, and dam storage high. Releases should be timed to coincide with, and therefore supplement, high flows in tributaries. Knowledge of the minimum discharge and duration required to fill wetlands can be obtained by appropriate hydrologic modelling. The idea of special environmental floods is being undertaken or seriously considered in Australia (Australian Water and Wastewater Association 1995) and other parts of the world (Walmsley and Davies 1989). However, this approach would not generally be applicable to systems which have temperature-sensitive species and which are impounded by a deep-release reservoir (Gippel and Finlayson 1993).

Local approach

If uncontrolled regional flooding is unacceptable, or the disturbance to natural inflows is otherwise irreversible, then artificial watering of particular wetlands can be considered. Possible sources are groundwater, a local surface supply (Rhoads and Miller 1990), or an external catchment area such as a road surface (Gippel 1993). In irrigation areas, channels and other irrigation infrastructure would be ideal for supplying water to wetlands. It may be necessary to construct a water level regulating structure on the wetland outlet. Other options are to modify the wetland inlet, or to construct embankments which either prevent excess water from entering the wetland, or retain water that would otherwise drain (Gippel 1993).

A hydrological investigation will provide objective information for guiding the management of wetland water requirements. However, a regular annual cycle based on the average condition is rarely desirable. Normal wetland functioning relies on exposure to the full range of hydrological conditions. For example, average conditions may maintain plant growth, but an extreme event may be required for propagation. Wetland environments can be stable (Niering 1988: 50) or dynamic (Larson and Golet 1982) in the long term, but much short-term variability in the hydrologic regime is normally superimposed over long-term trends (Stone 1989). Where the natural regime is characterised by high variability, then water level manipulation should be managed accordingly.

4.5.2 Hydrological manipulation of wetlands

Where restoration of the natural hydrological regime is either impractical or undesirable, the objective of management may be to maintain a particular ecological condition. Having selected the desired wetland ecological type, managers can manipulate the water regime to suit the known water requirements of key species or communities. For example, for Hird and Johnsons Swamps, Victoria, CNR (undated) recommended drying every four years to control carp, rapid filling to control the spread of typha, and periodic drying to favour the breeding of preferred waterbird species.

Pumps (Rhoads and Miller 1990), runoff directed from external catchments (Gippel 1993), regulating structures, or embankments can be used to control the water level as desired (Atkins 1993). The uncertainty with this type of environmental manipulation is that information on water requirements of particular species is usually incomplete.

4.5.3 Water requirements of wetland flora and fauna

Published information on water requirements of particular species or communities is often based on averaged data, or short-term experiments. Natural hydrologic conditions occasionally produce extreme conditions which are very important to the maintenance of a wetland's biological integrity. Average hydrologic conditions may be adequate for maintaining plant growth, but propagation may rely on an extreme event or combination of extreme events. For some wetlands then, repeated application of a hydrologic regime which reflects average conditions will lead to a decline in ecological status.

Some research has been done overseas on the flooding tolerance of wetland vegetation species, and while much of it has no direct relevance to Australian wetland species, some of the plants are common [for example, see Shay and Shay (1986) for water requirements of *Phragmites* and *Typha* spp.]. The literature does provide useful methodological guidelines and should be consulted if undertaking this type of research.

Many species of flora and fauna have been recorded in Australian wetlands. Kinhill Engineers Pty Ltd (1988) prepared a representative list of plant communities/species that rely on periodic or permanent inundation, or seasonally elevated watertables. The list contains information on the basic hydrological requirements of these species. However, the information is sketchy and incomplete. There is good information on the requirements of River Red Gum (Eucalyptus camaldulensis) forests and associated wetlands (Kinhill Engineers Pty Ltd 1988, Leitch 1989; McCosker and Duggin 1993, Ward et al. 1994). River Red Gum requires inundation every 2-3 years, while Juncus ingens (Giant Rush) Eleocharis acuta (Spike Rush), and Pseudoraphis spinescens (Moira Grass) require more frequent flooding (annual) and a longer duration of inundation of 4-9 months. In contrast, in the Gwydir wetlands of northern NSW, Coolabah (Eucalyptus coolabah), requires flooding only once every 10-20 years (Bennett and McCosker 1994).

Briggs (1988) specified water requirements for waterbirds in southern NSW. The recommendations include: drying every five years for at least three months; inundation should occur in early spring; inundation duration should preferably range from four to six months, not exceed four years and not be less than two months. More detailed information is provided in Kinhill Engineers Pty Ltd (1988).

Kinhill Engineers Pty Ltd (1988) discuss the hydrological requirements of wetland fish, invertebrates, frogs, reptiles and mammals. More detailed information on fish requirements can be found in Koehn and O'Connor (1990).

4.6 BASIC COMPONENTS OF A WATER MANAGEMENT PLAN

4.6.1 Management Objectives

Managing disturbed wetlands with high natural value

Ideally, reinstate the natural hydrological regime by removing disturbing factors. If this is not feasible, manipulate the water supply to mimic the natural hydrological regime.

Managing other wetlands

Conserve the existing ecological or hydrological processes by managing the water supply according to the current hydrological regime.

Establish a desired ecological or hydrological condition by managing the water supply according to known water requirements of key species and communities, or to suit the desired land use.

Assessing impacts of proposed developments

Predict the impact of a proposed development (such as a drainage scheme) on wetland hydrology and, using knowledge of water requirements of key species and communities, thenforecast likely changes in wetland ecological condition.

Predicting changes in disturbed wetlands if unmanaged

For wetlands which are adjusting to a recent hydrological disturbance, knowing the natural and current (disturbed) regime, and using knowledge of water requirements of key species and communities, *forecast likely changes in wetland ecological condition.*

4.6.2 Specification of proposed water regime

The proposed water regime should be specified in detail using the indices of flooding and drying recommended in this document. Any alterations to the current regime should be specified.

4.6.3 Assessment of benefits and disadvantages

Benefits and disadvantages to any traditional or proposed form of wetland use arising from the proposed water regime should be assessed.

4.6.4 Specification of works and allocations

Estimate the cost of proposed works and specify the water allocations required (quantity, frequency and timing).

4.6.5 Monitoring program

A wetland water management plan should incorporate a monitoring program. Ideally this will involve time series measurement of the components of the water budget, but the most useful information is water level. Measurements should be made at least monthly. Weekly measurements would provide better information, but in most cases the additional data from more frequent measurements would not be useful for management purposes. Water level can be simply read from a gauge plate. However, it may be more time and cost efficient to establish a digitally logged, continuously recording water-level meter. The hydrological monitoring program should be accompanied by a biological, and perhaps geomorphical monitoring program (Coates *et al.* 1989, Rhoads and Miller 1990).

4.7 REFERENCES AND BIBLIOGRAPHY

Alexander, G.N. 1971. Effect of catchment area on flood magnitude. Hydrology Papers *1971.* Institution of Engineers Australia, Sydney, 96-110.

Anderson, M.P. and Munter, J.A. 1981. Seasonal reversals of groundwater flow around lakes and the relevance to stagnation points and lake budgets. Water Resources Research 17:1139–1150.

Arumugam, P.T. and Geddes, M.C. 1987. Feeding and growth of golden perch larvae and fry *(Macquaria* ambigua . Trans. Roy. Soc. South Aust. 11:59–65.

Atkins, B. 1993. Final report: integrated watering strategy for mid-Murray wetlands (IWS). Integrated Watering Strategy Report No. *2.* Floodplain Ecology Group, Department of Conservation and Natural Resources, North East Area, Victoria, Australia.

Australian Biological Research Group (undated). Conservation Values of Lakes and Wetlands in South-Western Region Victoria—Technical Report. Report to Department of Water Resources Victoria, Conservation Forests and Lands and Ministry for Planning and Environment.

Australian Water and Wastewater Association Inc. 1994. Environmental Flows Seminar, Proceedings. August 25-26, Canberra, AWWA, Artarmon, NSW, Australia.

Australian Water Resources Council 1982. Stream Gauging Information, Australia 5th ed. Department of National Development and Energy, Water Resources Series No 1, Canberra, Australia.

Barnes, H.H. 1967. Roughness characteristics of natural channels. United States Geological Survey, Water Supply Paper *1849.*

Bedinger, M.S. 1978. Relation between forest species and flooding. In: Greeson, P.E., Clark, J.R. and Clark, J.E. (eds). Wetland Functions and Values: The State of Our Understanding. Proceedings of the National Symposium on Wetlands, 7-10 November, Disneyworld Village, Lake Buena Vista, Florida, American Water Resources Association, Minneapolis, Minnesota, USA, pp. 427-435.

Bedinger, M.S. 1979. Forests and flooding with special reference to the White River and Ouachita River basins, Arkansas. United States Geological Survey, Water Resources Investigation Open File Report *79-68.*

Bennett, M. and Green, J. 1993. A *Preliminary* Estimate of *Gwydir* Wetlands Water Needs. Department of Water Resources, Sydney, Australia.

Bennett, M. and McCosker, R. 1994. Estimating environmental flow requirements of wetlands. Environmental Flows Seminar, Proceedings, August 25-6, Canberra, Australian Water and Wastewater Association Inc., Artarmon, NSW, Australia, 9-16.

Beovich, E. 1994. Lindsay Island: Background Paper And Interim Water Management Strategy. Department of Conservation and Natural Resources, Mildura, Victoria, Australia.

Beovich, E.K. and Lloyd, L.N. 1993a. Bruces Bend State Forest interim water management strategy. Integrated Watering Strategy Report No. *8,* Floodplain Ecology Group, Department of Conservation and Natural Resources, North East Area, Victoria, Australia.

Beovich, E.K. and Lloyd, L.N. 1993b. Lake Moodemere Interim Water Management Strategy. Integrated Watering Strategy Report No. *9,* Floodplain Ecology Group, Department of Conservation and Natural Resources, North East Area, Victoria, Australia.

Bevan, K.J. and Binley, A.M. 1992. The future of distributed models: model calibration and predictive uncertainty. *Hydrological Processes* 6:279-298.

Bewsher, A., Macleod, D.J., Francis, R.I., Tilleard, J. and Elphinstone, R. 1991. Water management of the Barmah-Millewa Forests. *International Hydrology and Water Resources Symposium, Perth, The Institution of Engineers Australia, National Conference Publication No. 91/22,* Vol. 3, 880-885.

Blasco, F., Bellan, M.F. and Chaudhury, M.U. 1992. Estimating the extent of floods in Bangladesh using SPOT data. *Remote Sensing of Environment* 39:167-178.

Boon, P.I. 1990. Organic matter degradation and nutrient regeneration in Australian freshwaters. II. Spatial and temporal variation, and relation with environmental conditions. *Arch. Hydrobiol.* 117:405-436.

Boon, P.I. 1991. Bacterial assemblages in rivers and billabongs of southeastern Australia. *Microbial Ecology* 22:27-52.

Boto, K.G. and Patrick, Jr., W.H. 1978. Role of wetlands in the removal of suspended solids. In: Greeson, P.E., Clark, J.R. and Clark, J.E. (eds). *Wetland Functions and Values: The State of Our Understanding.* Proceedings of the National Symposium on Wetlands, 7-10 November, Disneyworld Village, Lake Buena Vista, Florida, American Water Resources Association, Minneapolis, Minnesota, USA: 479-489.

Boulton, A.J. and Lloyd, L.N. 1992. Flooding frequency and invertebrate assemblages emerging from floodplain sediments at Chowilla, lower River Murray, South Australia. *Regulated Rivers* 7:137-151.

Bren, L.J. 1987. The duration of inundation in a flooding river red gum forest. *Australian Forest Research* 17:191-202.

Bren, L.J. 1988a. Flooding characteristics of a riparian red gum forest. *Australian* Forestry 51:57-62.

Bren, L.J. 1988b. Effects of river regulation on flooding of a riparian red gum forest on the River Murray, Australia. *Regulated Rivers: Research and Management* 2:65-77.

Bren, L.J. and Gibbs, N.L. 1986. Relationships between flood frequency, vegetation and topography in a river red gum forest. *Australian Forest Research* 16:357-370.

Brereton, G.J. 1993. *The History of Investigations into the Macquarie Marshes.* Natural Resources Management Strategy, Murray-Darling Basin Commission, Canberra, ACT, Australia.

Bridgham, S.D., Faulkner, S.P., and Richardson, C.J. 1991. Steel rod oxidation as a hydrologic indicator in wetland soils. *Soil Sci Soc Am. J.* 55:856-862.

Briggs, S.V. 1988. Guidelines for management of inland wetlands in southern New South Wales. *Wetlands (Australia)* 8:1-2.

Briggs, S.V. and Maher, M.T. 1985. Limnological studies of waterfowl habitat in south-western New South Wales II Aquatic macrophyte productivity. *Australian Journal Marine Freshwater Research* 36:707-715.

Briggs, S.V., Maher, M.T. and Carpenter, S.M. 1985. Limnological studies of waterfowl habitat in south-western New South Wales. *Aust. J. Mar. Freshw. Res.* 36:59-67.

Brizga, S.O. and Finlayson, B.L. 1990. Channel avulsion and river metamorphosis: the case of the Thomson River, Victoria, Australia. *Earth Surface Processes and Landforms* 15:391-404.

Brookes, A. Gregory, K.J. and Dawson, F.H. 1983. An assessment of river channelisation in England and Wales. *The Science of the Total Environment* 27:97-111.

Brown, M.T. 1988. A simulation model of hydrology and nutrient dynamics in wetlands. *Comput. Environ. Urban Syst.* 12:221-237.

Brown, R.G., Stark, J.R. and Patterson, G.L. 1988. Ground-water and surface-water interactions in Minnesota and Wisconsin wetlands. In: Hook, D.D *et al.* (eds). *The Ecology and Management of Wetlands, Volume 1: Ecology of Wetlands.* Croom Helm, Timber Press, Portland USA, 176-180.

Brownlow, M.D., Sparrow, A.D., and Ganf, G.G. 1994. Classification of water regimes in systems of fluctuating water level. *Aust. J. Mar. Freshwater Res.* 45:1375-1385.

Brutsaert, W. and Yeh, G. 1970. Implications of a type of empirical evaporation formula for lakes and pans. *Water Resources Research* 6:1202-1215.

Bureau of Meteorology 1985. *Flood Classes for Victorian River Gauges.* Commonwealth of Australia.

Bureau of Meteorology 1988. *Climatic Atlas of Australia.* Australian Government Publishing Service.

Burke, D.G., Meyers, E.J., Tiner, R.W. and Groman, H. 1988. What are wetlands, and why are they important? Ch. 1 In: *Protecting Non tidal Wetlands,* Planning Advisory Service Report Number 412/413, American Planning Association, Chicago, Illinois, USA, 1-16.

Carter, V. 1986. An overview of the hydrologic concerns related to wetlands in the United States. *Canadian Journal of Botany* 64:364-374.

Carter, V., Bedinger, M.S., Novitzki, R.P. and Wilen, W.O. 1979. Water resources and wetlands. In Greeson, P.E., Clark, J.R. and Clark, J.E. (eds). *Wetland Functions and Values:The State of Our Understanding.* American Water Resources Association, Minneapolis, MN, USA, 344 376.

Casanova, M.T. 1994. Vegetative and reproductive responses of charophytes to water-level fluctuations in permanent and temporary wetlands in Australia. *Aust. J. Mar. Freshwater Res.* 45:1409-19.

CFL, 1988. *Wetlands Conservation Program for Victoria.* Department of Conservation, Forests and Lands, Victoria.

CFL, Water Victoria & Ministry for Planning and Environment 1988. *Wetlands Conservation Program for Victoria.* Government of Victoria, Melbourne.

Chesterfield, E.A. 1986. Changes in the vegetation of the river red gum forest at Barmah, Victoria. *Australian Forest Research* 49:4-15.

Chiew, F.H.S., Stewardson, M.J. and McMahon, T.A. 1993. Comparison of six rainfall-runoff modelling approaches. *Journal of Hydrology* 147:1-36.

Chow, V.T. 1959. *Open Channel Hydraulics.* McGraw-Hill, New York, USA.

Clark, J.R. and Benforado, J. 1981. *Wetlands of Bottomland Hardwood Forests.* Elsevier Publ. Co., New York, USA.

CNR (undated). *Draft-Hird and Johnson Swamps, Interim Management Statement.* Department of Conservation and Natural Resources, Bendigo Region, Victoria. (unpublished).

Coates, R., Swanson, M. and Williams, P. 1989. Hydrologic analysis for coastal wetland restoration. *Environmental Management* 13:715-727.

Cooling, M. 1993. Limlog:Hydro-ecological management of rivers and wetlands. *Integrated Watering Strategy Report No.* 6, Floodplain Ecology group, Department of Conservation and Natural Resources, North East Area, Victoria, Australia.

Cordery, I., Pilgrim, D.H. and Baron, D.C. 1980. Validity of use of small catchment research results for large basins. In: Proceedings Hydrology and Water Resources Symposium, Adelaide. The Institution of Engineers Australia, *National Conference Publication No. 80/9,* 172-177.

Corrick, A.H. 1981. Wetlands of Victoria II Wetlands and waterbirds of South Gippsland. *Proc. R. Soc. Vic.* 92:187-200.

Corrick, A.H. 1982. Wetlands of Victoria III Wetlands and waterbirds between Port Phillip Bay and Mount Emu Creek. *Proc. R. Soc. Vic.* 94:69-87.

Corrick, A.H. and Norman, F.I. 1980. Wetlands and waterbirds of the Snowy River and Gippsland Lakes Catchment. *Proc. R. Soc. Vic.* 91:1-15.

Crome, F.H.J. 1988. To drain or not to drain? Intermittent swamp drainage and waterbird breeding. *The Emu* 88:243-248.

DCE and Office of the Environment 1992. *An Assessment of Victoria's Wetlands.* Department of Conservation and Environment, Victoria, Australia.

Deacon, N.H.G. 1984. Seepage and durability of irrigation canal linings: a review of published data. *Technical Note* OD/TN5. Hydraulics Research, Wallingford, Oxfordshire, UK.

Denton, M and Ganf, G.G. 1994. Response of juvenile *Melaleuca halmaturorum* to flooding: management implications for a seasonal wetland, Bool Lagoon, South Australia. *Aust. J. Mar. Freshwater Res.* 45:1395-408.

Department of Water Resources 1990. *'Pineena': A CD-ROM Water Data System.* New South Wales Department of Water Resources, Sydney, Australia.

Dewar, R.W. and Robinson, D.K. 1988. An investigation into lag times from an urban catchment. In: Proceedings Hydrology and Water Resources Symposium, Canberra, The Institution of Engineers Australia. *National Conference Publication No. 88/1,* 182-186.

Dexter, B.D., Rose, H.J. and Davies, N. 1986. River regulation and associated forest management problems in the River Murray red gum forests. *Australian Forestry* 49:16-27.

Dooge, J. 1972. The water balance of bogs and fens (review report). In *Hydrology of Marsh-Ridden Areas,* Proceedings of the Minsk Symposium, 1972, UNESCO Press, Paris, 233-271.

Dooge, J. 1975. The water balance of bogs and fens. In: *Hydrology of Marsh-Ridden Areas,* Proceedings of the Minsk Symposium, 1972, The UNESCO Press, Paris, France, 233-271.

Duever, M.J. 1988a. Hydrologic processes for models of freshwater wetlands. In: Mitsch, W.J., Straskraba, M. and Jorgensen, S.E. (eds). *Wetland Modelling,*

Developments in Environmental Modelling, Vol. 12. Elsevier, Amsterdam, The Netherlands, 9-39.

Duever, M.J. 1988b. Surface hydrology and plant communities of Corkscrew Swamp. **In:** Wilcox, D.A. (ed). **Interdisciplinary Approaches to Freshwater Wetlands Research.** Michigan State University Press, East Lansing, Michigan, USA, 97-118.

Duever, M.J., McCollom, J. and Neuman, L. 1987. Plant community boundaries and water levels at Lake Hatchineha, Florida. In: Kusler, J.A. and Brooks, G. (eds). **Wetland Hydrology.** Proceedings of the National Wetland Symposium, Association of State Wetland Managers, Berne, NY, USA, 67-72.

Dwyer, K. and Bennett, M. 1988. **Hydrology and water management *capability* of the Booligal Wetlands 1986 flood.** Department of Water Resources New South Wales Technical Services Division, Parramatta, NSW, Australia.

Ehrnfeld, J.G. and Schneider, J.P. 1991. **Chaemaecyparis thyoides** wetlands and suburbanization: effects on hydrology, water quality and plant community composition. **Journal of Applied Ecology** 28:467-490.

Erskine, W.D. and Warner, R.F. 1988. Geomorphic effects of alternating flood- and drought-dominated regimes on NSW coastal rivers. In: Warner, R.J. (ed). **Fluvial Geomorphology of Australia,** Academic Press, Sydney, Australia, 223-244.

Erskine, W.D., Rutherford, I.D. and Tilleard, J.W. 1990. **Fluvial Geomorphology of the Tributaries to the Gippsland Lakes.** Ian Drummond and Associates Pty Ltd for Department of Conservation and Environment, East Melbourne, Victoria, Australia.

Erwin, K.L. 1990. Wetland evaluation for restoration and creation. In: Kusler, J.A. and Kentula, M.E. (eds). **Wetland Creation and Restoration:The Status of the Science.** Washington, D.C., USA, 429-458

Finlayson, B.L. and McMahon, T.A. 1988. Australia v the world:a comparative analysis of streamflow characteristics. In Warner, R.J. (ed.) **Fluvial Geomorphology of Australia.** Academic Press Australia, 17-40.

Gehrke, P.C. 1990. Spatial and temporal dispersion patterns of Golden Perch, **Mac quaria ambigua,** larvae in an artificial floodplain environment. **Journal of Fish Biology** 37:225-236.

Gill, C.J. 1970. Flooding tolerance of woody species-a review. ***Forestry* Abstracts** 31:671-688.

Gilman, K. 1994. **Hydrology and Wetland Conservation,** Water Science Series. Chichester, NY.

Gippel, C.J. 1993. Hydrological management of a lake with floating islands near Pirron Yallock, Victoria. Australia **Journal Environmental Management** 37:219-238.

Gippel, C.J. 1995. Environmental hydraulics of large woody debris in streams and rivers. **Journal of Environmental Engineering** 121:388-395.

Gippel, C.]. and Finlayson, B.L. 1993. Environmental impacts of regulation of the Goulburn River, Victoria. In: Proceedings Hydrology and Water Resources Conference, Newcastle, The Institution of Engineers Australia, **National Conference Publication No. 93/14,** 33-38.

Gippel, C.J. and Stewardson, M.J. 1995. Development of an environmental flow management strategy for the Thomson River, Victoria, Australia. *Regulated Rivers: Research and Management* 11: (in press).

Gippel, Finlayson, B.L. and Thompson, B.H. 1991. Establishing the effect of river regulation on wetland flooding regimes, Part II. In: *Rapid Techniques for Assessing Wetland Vegetation and Water Regime, Working Paper No. WP/12/91,* Bureau of Rural Resources, Department of Primary Industries and Energy, Canberra, ACT, 89-129.

Good, R.E., Whingham, D.F. and Simpson, R.L. 1978. *Freshwater Wetlands.* Academic Press, N.Y., USA.

Gopal, B., Turner, R.E., Wetzel, R.G., and Whigham D.F. 1982. *Wetlands: Ecology and Management.* In: Proceedings of the First International Wetlands Conference, 10-17 September 1980, New Delhi, India, National Institute of Ecology, University of Rajasthan, Jaipur, and International Scientific Publications, Jaipur, India, 181-185.

Gordon, N.D., McMahon, T.A. and Finlayson, B.L. 1992. *Stream Hydrology: An Introduction for Ecologists.* John Wiley and Sons Ltd., Chichester, UK..

Gosselink, J.G. and Turner, R.E. 1978. The role of hydrology in freshwater wetland ecosystems. In: Good, R.E., Whigham, D.F., Simpson, R.L. and Jackson, Jr., C.G. (eds). *Freshwater Wetlands: Ecological Processes and Management Potential.* Proceedings of the Symposium on Freshwater Marshes: Present Status, Future Needs, February 1977, Rutgers University, New Brunswick, New Jersey, USA, Academic Press, New York, USA, 63-78.

Graf, W.L. 1980. Riparian management: a flood control perspective. *Journal of Soil and Water Conservation* 35:158-161.

Grayson, R.B., Moore, I.D. and McMahon, T.A. 1992. Physically based hydrologic modelling 2. Is the concept realistic. *Water Resources Research* 28:2659-2666.

Greeson, P.E., Clark, J.R. and Clark, J.E. 1979. *Wetlands Functions and Values: The State of Our Understanding.* American Water Resources Association, Minneapolis, MN, USA.

Gunderson, L.H, Stenberg, J.R., and Herndon, A.K. 1988. Tolerance of five hardwood species to flooding regimes In: Wilcox, D.A. (ed). *Interdisciplinary Approaches to Freshwater Wetlands Research,* Michigan State University Press, East Lansing, Michigan, USA, 119-132.

Gunnison, D., Engler, R.M. and Patrick, W.H. Jr. 1985. Chemistry and microbiology of newly-flooded soils: relationship to reservoir water quality. In: Gunnison, D. (ed). *Microbial Processes in Reservoirs.* Junk, Dordrecht, 39-57.

Gutteridge Haskins and Davey Pty Ltd 1991a. *Water Supply Options for the Lower Latrobe River Wetlands,* Report to the Latrobe Region Water Authority, Victoria, Australia.

Gutteridge, Haskins and Davey Pty Ltd 1980. *The Waters of the Western District Lakes,* Public Review Draft, Draft Environment Protection Policy No.W-34B. Environment Protection Authority of Victoria, Melbourne, Australia.

Gutteridge, Haskins and Davey Pty Ltd 1991b. *Integrated Quantity/Quality Modelling-Stage 3.* Report to the Department of Water Resources, Sydney, Australia.

Haan, C.T., Johnson, H.P. and Brakenseik, D.L. 1982. Hydrological Modeling of Small Watersheds. American Society of Agricultural Engineers, Monograph No. 5.

Heinselman, M.L 1970. Landscape evolution, peatland types, and the environment in the Lake Agassiz Peatlands Natural, Area, Minnesota. Ecol. Monogr. 40:235-261.

Heron, S., Robley, A., Robb, B., and Johnson, P. 1991. Environmental assessment for the Avon-Richardson Land and Water Management Plan. Technical Report No. 3, Department of Conservation and Environment, Bendigo Region, Victoria, Australia.

Hicks, D.M. and Mason, P.D. 1991. Roughness Characteristics of New Zealand Rivers. Water Resources Survey, DSIR Marine and Freshwater, New Zealand.

Hindall, S.M. 1975. Measurement and prediction of sediment yields in Wisconsin streams, US Geological Survey Water Resources Investigations 54-75.

Hollands, G.G. 1987. Assessing the relationship of groundwater and wetlands. In: Kusler, J.A. and Brooks, G. (eds). Wetland Hydrology. Proceedings of the National Wetland Symposium, Association of State Wetland Managers, Berne, NY, USA, 240-242.

Hopkinson, Jr., C.S., and Day, Jr., J.W. 1980a. Modeling the relationship between development and storm water and nutrient runoff. Environmental Management 4:315-324.

Hopkinson, Jr., C.S., and Day, Jr., J.W. 1980b. Modeling hydrology and eutrophication in a Louisiana swamp forest ecosystem. Environmental Management 4:325-335.

Hounam, C.E. 1973. Comparison between pan and lake evaporation. World Meteorological Organization, Technical Note 126.

Hoy, R.D. and Stephens, S.K. 1979. Field study of lake evaporation-analysis of data from phase 2 storages and summary of phase 1 and phase 2. Australian Water Resources Council Technical Paper No. 41. Department National Development, Australian Water Resources Council, Australian Government Publishing Service, Canberra, ACT., Australia.

Hudson, N. 1981. Soil Conservation. Batsford Academic and Educational, London, UK..

Hutchinson, M.F. 1989. A new objective method for spatial interpolation of meteorological variables from irregular networks applied to the estimation of monthly mean solar radiation, temperature, precipitation and windrun. In: CSIRO Division of Water Resources Tech. Memo 89/5, 95-104.

Institution of Engineers, Australia 1987. Australian Rainfall and *Runoff*: A Guide to Flood Estimation. Pilgrim D.H. (ed). Institution of Engineers, Canberra, Australia, (2 Vols).

Ivanov, K.E. 1981. Water Movement in Mirelands. Academic Press, NY, USA

Jacobs, M.R. 1955. Growth Habits of the Eucalypts. Australian Government Printing Service, Canberra, A.C.T., Australia.

Jensen, A., Nicolson, C. and Carter J. 1994. Preservation and management of natural wetlands in the South Australian Murray Valley. Wat. Sci. Tech. 29:325-333.

Junk, W.J., Bayley, P.B. and Sparks, R.E. 1989. The flood pulse concept in river-floodplain systems. Special Publication of the Canadian Journal of Fisheries and Aquatic Sciences 106:110-127.

Kadlec, R.H. 1978. Wetlands for tertiary treatment. In: Greeson, P.E., Clark, J.R. and Clark, J.E. (eds). Wetland Functions and Values:The State of Our Understanding. Proceedings of the National Symposium on Wetlands, 7-10 November, Disneyworld Village, Lake Buena Vista, Florida, American Water Resources Association, Minneapolis, Minnesota, USA, 490-504.

Kadlec, R.H. 1990. Overland flow in wetlands:vegetation resistance. Journal of Hydraulic Engineering 116:691-706.

Kadlec, R.H. and Hammer, D.E. 1988. Modelling nutrient behaviour in wetlands. Ecol. Modelling 40:37-66.

Kadlec, R.H. and Kadlec, J.A. 1978. Wetlands and water quality. In Greeson, P.E., Clark, J.R. and Clark, J.E. (eds). Wetland Functions and Values:The State of Our Understanding. Proceedings of the National Symposium on Wetlands, 7-10 November, Disneyworld Village, Lake Buena Vista, Florida, American Water Resources Association, Minneapolis, Minnesota, USA, 436-456.

Kadlec, R.H., Williams, R.B. and Scheffe, R.D. 1988. Wetland evapotranspiration in temperate and arid climates. In: Hook, D.D et al. (eds). The Ecology and Management of Wetlands, Volume 1:Ecology of Wetlands. Croom Helm, Timber Press, Portland USA, 146-160.

Kallemeyn, L.W., Reiser, M.H., Smith, D.W. and Thurber, J.M. 1988. Effects of regulated lake levels on the aquatic ecosystem of Voyageurs National Park. In: Wilcox, D.A. (ed). Interdisciplinary Approaches to Freshwater Wetlands Research. Michigan State University Press, East Lansing, Michigan, USA, 133-146

Keyte, P.A. 1994. Lower Gwydir Wetland Plan of *Management—1994–1997*. Report to the Lower Gwydir Wetland Steering Committee, N.S.W. Department of Water Resources, Sydney, Australia.

Kinhill Engineers Pty Ltd 1988. Techniques for determining environmental water requirements—a review. A Report to the Department of Water Resources Victoria. Technical Report Series, Report No. 40, Department of Water Resources Victoria, Australia.

Klaassen, G.J. and van der Zwaard, J.J. 1973. Roughness coefficients of vegetated flood plains. Journal of Hydraulic Research 12:43-63.

Klimas, C.V. 1987. Forested buffers for overbank flow velocity reduction along the Lower Mississippi River. In Kusler, J.A. and Brooks, G. (eds). Wetland Hydrology. Proceedings of the National Wetland Symposium, Association of State Wetland Managers, Berne, NY, USA, 152-155.

Klimas, C.V. 1988. River regulation effects on floodplain hydrology and ecology. In Hook, D.D et al. (eds). The Ecology and Management of Wetlands, Volume 1: Ecology of Wetlands. Croom Helm, Timber Press, Portland USA, 40-49.

Klopatek, J.M. 1978. Nutrient dynamics of freshwater riverine marshes and the role of emergent macrophytes. In: Good, R.E., Whigham, D.F., Simpson, R.L. and Jackson, Jr., C.G. (eds). Freshwater Wetlands:Ecological Processes and Management Potential. Proceedings of the Symposium on Freshwater Marshes:Present Status, Future Needs, February 1977, Rutgers University, New Brunswick, New Jersey, USA, Academic Press, New York, USA, 195-216.

Koehn, J.D. and O'Connor, W.G. 1990. *Biological Information for Management of Native Freshwater Fish in Victoria.* Freshwater Fish Management Branch, Arthur Rylah Institute for Environmental Research, Department of Conservation and Environment, Victoria.

Kusler, J.A., 1987. Hydrology: an introduction for wetland managers. In: Kusler, J.A. and Brooks, G. eds). *Wetland Hydrology.* Proceedings of the National Wetland Symposium, Association of State Wetland Managers, Berne, NY, USA, 4-24.

LaBaugh, J.W. 1986. Wetland ecosystem studies from a hydrologic perspective. *Water Resources Bulletin* 22:1-10.

Lake, J.S. 1967a. Rearing experiments with five species of Australian freshwater fishes. I. Inducement to spawning. Aust. *J. Mar. Freshwater. Res.* 18:137-53.

Lake, J.S. 1967b. Rearing experiments with five species of Australian freshwater fishes. II. Morphogenesis and Ontogeny. Aust.J. *Mar. Freshwater. Res.* 18:155-73

Lane, A.P. 1982. Aspects of wetland hydrology in Victoria, coastal New South Wales and Queensland. *Technical memorandum* 82/15, CSIRO, Institute of Biological Resources, Division of Water and Land Resources, Canberra, ACT, Australia.

Larson, J.S. and Golet, F.C. 1982. Models of freshwater wetland change in southeastern New England. In Gopal, B., Turner, R.E., Wetzel, R.G., and Whigham D.F. (eds). *Wetlands:Ecology and Management.* Proceedings of the First International Wetlands Conference, 10-17 September 1980, New Delhi, India, National Institute of Ecology, University of Rajasthan, Jaipur, and International Scientific Publications, Jaipur, India, 181-185.

Lee, D.R. 1977. A device for measuring seepage flux in lakes and estuaries. Limnology *and Oceanography* 22:140-147.

Leitch, C. 1989. *Towards a strategy for managing the flooding of* Barmah *Forest.* Presented at the Seminar on Barmah Forest organised by the State Working Group on River Murray Wetland and Forest Management, Department of Conservation Forests and Lands, Benalla Region, Victoria, Australia.

Leitman, H.M., Sohm, J.E. and Franklin, M.A. 1982. Wetland hydrology and tree distribution of Apalachicola River flood plain, Florida. *United States Geological Survey, Open File Report* 82-251.

Lillehammer, A. and Saltveit, S.J. 1984. *Regulated Rivers.* Universitetsforlaget AS, Toyen, Norway.

Lloyd, L., Puckridge, J. and Walker, K. 1991. The significance of fish populations in the Murray-Darling system and their requirements for survival, Paper 10. In: Dendy, T. and Coombe, M. (eds). *Conservation in Management of the River Murray System—Making Conservation Count.* Proceedings of the Third Fenner Conference on the Environment, September, Canberra, South Australian Department of Environment and Planning, Adelaide, for Australian Academy of Science, South Australia, 86-99.

Lugg, A., Heron, S., Fleming, G. and O'Donnell, T. 1989. Conservation value of the wetlands in the Kerang Lakes area. *Report to* Kerang *Lakes Area Working Group,* Report 1, Kerang Lakes Assessment Group, Department of Conservation Forests and Lands, Victoria, Australia.

Lugg, A., Heron, S., O'Donnell, T., and Fleming, G. 1993. *Environmental Values And The Effects Of Salinity On The Flora And Fauna Of The Boort-West Of Loddon Catchment.* A Technical Report Produced for the Boort-West of Loddon Working Group, Department of Conservation and Natural Resources, Bendigo, Victoria, Australia.

Margules and Partners Pty Ltd 1989. *River Murray riparian vegetation study,* prepared with P and J Smith Ecological Consultants and the Department of Conservation, Forests and Lands for the Murray Darling Basin Commission, Canberra, ACT, Australia.

McComb, A.J. and Lake, P.S. 1988. The conservation and management of Australian wetlands, Ch. 9. In: McComb, A.J. and Lake, P.S. (eds). *The Conservation of Australian Wetlands.* Surrey Beatty and Sons Pty Ltd., New South Wales, Australia, 179–84.

McCosker, R.O. and Duggin, J.A. 1993. *Gingham Watercourse Management Plan—Final Report.* The University of New England, Armidale, N.S.W., Australia.

McKnight, J.S., Hook, D.D., Langdon, O.G. and Johnson, R.L. 1981. Flood tolerance and related characteristics of trees of the bottomland forests of the southern United States. In: Clark, J.R. and Benforado, J. (eds). *Wetlands of Bottomland Hardwood Forests.* Elsevier Scientific Publ. Co., New York, 29–70.

Michaelis, F.B. and O'Brien, M. 1988 Preservation of Australia's wetlands:a Commonwealth approach. In McComb, A.J. and Lake, P.S. (eds). *The Conservation of Australian Wetlands.* Surrey Beatty and Sons Pty Ltd., New South Wales, Australia, 167–77.

Mitsch, W.J. 1988. Productivity–hydrology–nutrient models of forested wetlands. In Mitsch, W.J., Straskraba, M. and Jorgensen, S.E. (eds). *Wetland Modelling.* Elsevier, Amsterdam, The Netherlands, 115–132.

Mitsch, W.J. and Reeder, B.C. 1991. Modelling nutrient retention of a freshwater coastal wetland:estimating the roles of primary productivity, sedimentation, resuspension and hydrology. *Ecological Modelling* 54:151–187.

Moore, P.D. 1975. Origin of blanket mires. *Nature* 256:267–269.

Morton, F.I. 1983a. Operational estimates of areal evapotranspiration and their significance to the science and practice of hydrology. *Journal of Hydrology* 66:1–76.

Morton, F.I. 1983b. Operational estimates of lake evaporation. *Journal of Hydrology* 66:77–100.

Nathan R.J. and McMahon T.A. 1991. *Estimating Low Flow Characteristics in Ungauged Catchments:A Practical Guide.* Department of Civil and Agricultural Engineering, University of Melbourne, Mighty Mouse, Melbourne, Australia.

Nathan, R. 1992. Environmental flows in the Goulburn River between Eildon and the Murray River: Impacts of Flow Regulation on the Hydrological Regime, *Investigations Branch Report No. 1992/09,* Rural Water Commission, Armadale, Victoria, Australia.

Nathan, R.J. and McMahon, T.A. 1990. *The Estimation of Low Flow Characteristics and Yield From Small Ungauged Rural Catchments.* Department of Civil and Agricultural Engineering, University of Melbourne, Melbourne, Australia.

Nathan, R.J., McMahon, T.A. and Brockwell, P.J. 1988. *Stochastic Generation of Rainfall and Evaporation Data for Lake Corangamite Catchment.* Final Report to Rural Water Commission, Department of Civil and Agricultural Engineering, University of Melbourne, Australia.

Nelson, K.D. 1985. *Design and Construction of Small Earth Dams.* Inkata Press, Melbourne.

Niering, W.A. 1988. Hydrology, disturbance and vegetation change. In Kusler, J.A. and Brooks, G. (eds). *Wetland Hydrology,* Proceedings of the National Wetland Symposium, Association of State Wetland Managers, Berne, NY, USA, 50-54.

Norman, F.I. and Corrick, A.H. 1988. Wetlands in Victoria: a brief review. In McComb, A.J. and Lake, P.S. (eds). *The Conservation of Australian Wetlands.* Surrey Beatty and Sons Pty Ltd., New South Wales, Australia, 17-34.

Novitski, R.P. 1978. Hydrologic characteristics of Wisconsin's wetlands and their influence on floods, stream flow, and sediment. In: Greeson, P.E., Clark, J.R. and Clark, J.E. (eds). *Wetland Functions and Values:The State of Our Understanding.* Proceedings of the National Symposium on Wetlands, 7-10 November, Disneyworld Village, Lake Buena Vista, Florida, American Water Resources Association, Minneapolis, Minnesota, USA, 377-388.

O'Brien, A.L. 1988. Evaluating the cumulative effects of alteration on New England wetlands. *Environmental Management* 12:627-636.

O'Shaughnessy, P.J. and Jayasuriya, M.D.A. 1991. Managing the ash type forests for water production in Victoria. In: McKinnell, F.H., Hopkins, E.R. and Fox, J.E.D. (eds). *Forest Management in Australia.* Surrey Beatty and Sons, Sydney, NSW, Australia, 341-363.

Paijmans, K., Galloway, R.W., Faith, D.P., Fleming, P.M., Haantjens, H.A., Heyligers, P.C., Kalma, J.D. and Loffler, E. 1985. Aspects of Australian wetlands. *Technical Paper No. 44,* Division of Water and Land Resources, Commonwealth Scientific and Industrial Research Organization, Australia.

Petts, G.E. 1984. *Impounded Rivers:Perspectives for Ecological Management.* Wiley-Interscience, Chichester, 27-53.

Pilgrim, D.H. 1983. Some problems in transferring hydrological relationships between small and large basins and between regions. *Journal of Hydrology* 65:49-72.

Pittock, A.B. 1975. Climate change and the patterns of variation in Australian rainfall. *Search* 6:498-504.

Pittock, A.B. 1983. Recent climatic change in Australia: implications for a CO_2-warmed earth. *Climatic Change* 5:321-340.

Pittock, A.B., Fowler, A.M. and Whetton, P.H. 1991. Probable changes in rainfall regimes due to the enhanced greenhouse effect. In: International Hydrology and Water Resources Symposium, Perth, The Institution of Engineers Australia, *National Conference Publication No. 91/22,* Vol. 1,182-186.

Raisanen, D.L., Leimer, S.D. and Textor, G.N. 1987. Hydroperiod prediction for four new palustrine wetlands. In Kusler, J.A. and Brooks, G. (eds). *Wetland Hydrology.* Proceedings of the National Wetland Symposium, Association of State Wetland Managers, Berne, NY, USA, 144-151.

Reinhart, K.G. and Eschner, A.R. 1962. Effect on streamflow of four different forest practices in the Allegheny Mountains. Journal of Geophysical Research 67:2433-2445.

Rhoads, B.L. and Miller, M.V. 1990. Impact of riverine wetlands construction and operation on stream channel stability:conceptual framework for geomorphic assessment. Environmental Management 14:799-807.

Ring, P.J. 1988. Long-term changes in storm runoff response in the Macintyre Valley, NSW. In Hydrology and Water Resources Symposium, Canberra, The Institution of Engineers Australia, National Conference Publication No. 88/1, 140-145.

Rood, S.B. and Heinz-Milne, S. 1989. Abrupt downstream forest decline following river damming in southern Alberta. Canadian Journal of Botany 67:1744-1749.

Rural Water Commission 1990. Victorian Surface Water Information to 1987. Rural Water Commission, Melbourne, Victoria, Australia, (4 Vols).

Schot, P.P., Barendregt, A. and Wassen, M.J. 1988. Hydrology of the wetland Naarderemeer: influence of the surrounding area and impact on vegetation. Agricultural Water Management 14:459-470.

Schouten, P.H., Verstraelen, P.J.T., and Buntsma, H. 1988. Restoration of the Vecht Lakes ecosystems surrounding the Horstermeer Polder: a feasibility study. Agricultural Water Management 14:471-479.

Schulze, R.E. and George, W.J. 1987. A dynamic, process-based, user-oriented model of forest effects on water yield. Hydrological Processes 1:293-307.

Serrano, L. 1992. Effecto los compuestos polifenolics, taninos y ligninas sobre las communidades plactonicas de las pagunas peridunares del Parque Nacional de Donana. PhD Thesis, University of Seville, Spain (unpublished, in Spanish).

Shaw, J., Beilharz, M., Hill, R., Polley, V. and Sullivan, C. 1990. An introduction to the Victorian Wetlands Conservation Program. In: Wetlands, Their Ecology, Function, Restoration and Management. Proceedings of the Applied Ecology and Conservation Seminal Series, Wildlife Reserves, Latrobe University, Oct-Dec 1989, Bundoora, Victoria, Australia, 3-14.

Shay, J.M. and Shay, C.T. 1986. Prairie marshes in western Canada, with specific reference to the ecology of five emergent macrophytes. Canadian Journal of Botany 64:443-454.

Shields, F.D. and Nunnally, N.R. 1984. Environmental aspects of clearing and snagging. Journal of Environmental Engineering 110:152-165.

Siegel, D.I. 1988. Evaluating cumulative effects of disturbance on the hydrologic function of bogs, fens, and mires. Environmental Management 12:621-626.

Skaggs, R.W., Amatya, D., Evans, R.O., and Parsons, J.E. 1994. Characterisation and evaluation of proposed hydrologic criteria for wetlands. J. Soil and Water Cons. 49:501-510.

Squires, L. and van der Valk, A.G. 1992. Water-depth tolerances of the dominant emergent macrophytes of the Delta Marsh, Manitoba. Canadian Journal of Botany 70:1860-1867.

Srikanthan, R. and Neil, D.T. 1988. Simulation of the effect of farm dams on water and sediment yield from two small rural catchments. Australian Journal of Soil and Water Conservation 2:40-45.

Stark, J.R. and Brown, R.G. 1987. Hydrology and water quality of a wetland used to receive wastewater effluent, St Joseph, Minnesota. In Kusler, J.A. and Brooks, G. (eds). *Wetland Hydrology.* Proceedings of the National Wetland Symposium, Association of State Wetland Managers, Berne, NY, USA, 197-204.

Stone, C.S. 1989. Process, stability, and management in wetlands. In: *Wetlands: Their Ecology, Function, Restoration and Management.* Proceedings of the Applied Ecology and Conservation Seminar Series, Wildlife Reserves, Latrobe University, Bundoora, Victoria, Australia, 47-53.

Suurballe, N.C. 1987. Hydrologic regime of a floodplain wetland in Massachusetts. In: Kusler, J.A. and Brooks, G. (eds). *Wetland Hydrology.* Proceedings of the National Wetland Symposium, Association of State Wetland Managers, Berne, NY, USA, 73-81.

Taylor, T.J. and Barclay, J.S. 1985. Renovation of a Plains State stream—physical problem solving. In: Riparian Ecosystems and their Management: Reconciling Conflicting Uses. First North American Riparian Conference, Tucson, Arizona, *USDA Forest Service General Technical Report* RM-120, 62-66.

Teskey, R.O. and Hinkley, T.M. 1977a. *Impact Of Water Level Changes On Woody Riparian And Wetland Communities. Volume I Plant And Soil Responses To Flooding.* Unites States Fisheries and Wildlife Service, Office for Biological Services 77/58.

Teskey, R.O. and Hinkley, T.M. 1977b. *Impact Of Water Level Changes On Woody Riparian And Wetland Communities. Volume II The Southern Forest Region.* United States Fisheries and Wildlife Service, Office for Biological Services 77/59.

Thornton, S.A. and Briggs, S.V. 1994. A survey of hydrological changes to wetlands of the Murrumbidgee River. *Wetlands (Australia)* 13:1-10.

Townley, L.R., Turner, J.V., Trefry, M.G. and Barr, A.D. 1991. Groundwater flow patterns around near lakes and wetlands: modelling and field validation. International Hydrology and Water Resources Symposium, Perth, The Institution of Engineers Australia, *National Conference Publication No.* 91/22, Vol. 3, 732-737.

Tunbridge, B.R. and Glenane, T.G. 1982. Fisheries value and classification of fresh and estuarine waters in Victoria. Fisheries and Wildlife Division, Ministry for Conservation, Melbourne, Australia.

United States Army Corps of Engineers 1990. Computing water surface profiles with HEC-2 on a personal computer, *Training Document No.* 26, US Army Corps of Engineers, Hydrologic Engineering Centre, Davis CA.

van der Molen, W.H. 1988. Hydrology of natural wetlands and wet nature reserves. *Agricultural Water Management* 14:357-364.

van der Valk, A.G. 1981. Succession in wetlands:a Gleasonian approach. *Ecology* 62:688-696.

van der Valk, A.G. 1987. Vegetation dynamics of freshwater wetlands:a selective review of the literature. Archiv *Fur* Hydrobiologie 27:27-39.

Wachyan, E. and Rushton, K.R. 1987. Water losses from irrigation canals. *Journal of Hydrology* 92:275-288.

Walmsley, R. D. and Davies, B.R. 1989. An overview of water for environmental management. *Fourth South African Hydrological Symposium,* 20-22 November, Pretoria, South Africa.

Ward, K.A., Leitch, C., Lloyd, L.N., and Atkins, B.P. 1994. Draft interim water management strategy for Barmah Forest, Victoria. *Integrated Watering Strategy Report No. 6,* Floodplain Ecology group, Department of Conservation and Natural Resources, North East Area, Victoria, Australia.

White, I. and Denmead, O.T. 1989. Point and whole basin estimates of seepage and evaporation losses from a saline groundwater-disposal basin. *Hydrology and Water Resources Symposium,* New Zealand Hydrological Society, University of Canterbury, Christchurch, N.Z., 361-366.

Whitlow, T.H. and Harris, R.W. 1979. Flood tolerance in plants: a state-of-the-art review. United States Army Engineers Waterways Experimental Station, *Technical Report E-79-2,* Vicksburgh, MS.

Winter, T.C. 1981. Uncertainties in estimating the water balance of lakes. *Water Resources Bulletin* 17:82-115.

Wisheu, I.C. and Keddy, P.A. 1989. The conservation and management of a threatened coastal plain plant community in eastern North America (Nova Scotia, Canada). *Biological Conservation* 48:229-238.

Wong, T.H.F. and Roberts, Z.A. 1991. Water management for wetlands, International Hydrology and Water Resources Symposium, Perth. The Institution of Engineers Australia, *National Conference Publication No. 91/22,* Vol. 2, 353-358.

Wong, T.H.F. and Wellington, N.B. 1990. Modelling water resource systems using HEC5Q. In: Conference on Hydraulics in Civil Engineering, Sydney, The Institution of Engineers Australia, *National Conference Publication No. 90/4,* 136-140.

Woo, M.K. and Rowsell, R.D. 1993. Hydrology of a prairie slough. *Journal of Hydrology* 146:175-207.

4.8 APPENDICES

Appendix 4a Flood frequency analysis

Flood frequency analysis enables estimation of the probability of the occurrence of floods of a selected magnitude. The main requirement is the availability of a good river gauging record. The methodology is very comprehensively detailed in Institution of Engineers, Australia (1987: 197-236) and Gordon *et al.* (1992: 351-373). The latter reference conveniently provides computer programs which perform the calculations and display the results graphically. The description below is necessarily brief and it is strongly recommended that one of the above texts be consulted prior to carrying out any analysis.

Two types of flood series can be analysed: annual and partial.

Annual flood series

The annual flood series is composed of the highest instantaneous rate of discharge in each year of record. The year may be a calendar year, or if the flow is highly seasonal then the water year should be used. This commences on the month corresponding to the end of the period of lowest average flow. The highest flow in each year is selected, and all other floods are neglected, so that for N years of record the annual flood series will have N values. The advantages of the annual series are: the flood events are likely to be independent; the data are readily available in hard copy form (eg Rural Water Commission 1990); and the analysis can be done with a calculator and plotted by hand. The disadvantage is that floods which occur with a frequency of greater than once per year are not considered. It is possible that some riverine wetlands are inundated more than once per year by independent events.

Partial flood series

The partial flood series consists of all floods with a peak discharge above a selected threshold value, regardless of the number of such floods occurring each year. In an investigation of wetland inundation, the threshold could be set at the discharge which is just sufficient to overtop the banks. The number of floods, K, will generally be different than the number of years of record, N. An advantage of the partial series is that small events which do not inundate wetlands are excluded from the analysis. However, a disadvantage is that the series must be extracted from the daily flow record, a task which requires the use of large data files and computer programs. If daily flow records are to be analysed then the methods described in Section 4.2 will provide more comprehensive and useful information than analysis of the partial flood series.

A major difficulty in selecting events for the partial series is applying a criterion for independence of successive peaks. A protracted flood event may consist of several peaks which exceed the threshold wetland inundation height, perhaps even receding below the banks between peaks. However, if the first flood peak fills the wetlands then the subsequent peaks have little hydrological significance. In a wetland environment it would take a reasonable length of time for post-inundation processes to become established and for evaporation to significantly lower the water level. In a study of Goulburn River wetlands, Gippel and Finlayson (1993)

nominally identified a wetland flood as being independent if it was separated by thirty flood-free days.

Calculation of plotting positions

Each value of discharge is plotted at a calculated value of annual exceedance probability (AEP) or average recurrence interval (ARI) on probability paper. A straight or curved line is fitted through the plotted points. It is recommended that an analytically fitted distribution, such as Log Pearson III, be used.

An unbiased estimate of the plotting position, $PP(m)$, **in terms of exceedance probability, of each observed value is given by the Weibull formula:**

$$PP(m)=\frac{}{N+1}$$

where

m = **rank of the flood in the series (where the largest flood has rank m = 1)**

N = **number of years of record**

Inversion of this equation will not result in unbiased plotting position ARIs. Institution of Engineers, Australia (1987) recommends the use of slightly different formulae.

5 LIVESTOCK GRAZING

5.1 INTRODUCTION

5.1.1 Grazing and wetlands

Grazing by native herbivores is a natural process in many wetland vegetation types, and in some wetlands appears to contribute to species and structural diversity (Brock[2] pers. comm.). Research has indicated that formerly grazed wetlands tend to become dominated by woody species or one or a few species of herbs or grasses when grazing is discontinued (Duncan, Brock and Scarlett pers comms). This tendency is a natural consequence of the behaviour of certain plant species. It is unusual for herbivores to stop grazing an area of their own accord, so grazing in some wetlands, even by hoofed domestic animals, may be more natural than no grazing.

The presence of water late in the growing season allows wetlands to continue producing green forage when vegetation growth in adjacent dryland communities slows or ceases due to summer drought. This forage, together with the palatability of aquatic and amphibious vegetation, the shade and shelter provided by fringing vegetation, and the presence of water, have made wetlands an attractive proposition for livestock grazing. Consequently, it is reasonable to assume that Australian wetlands have been grazed by domesticated herbivores since early in the process of European settlement, creating new patterns of grazing or introducing grazing to wetlands where it had not been a significant influence previously.

In recent years, the recognition that wetlands are a resource to be conserved has led to the realisation that although grazing can be a legitimate use or a significant management tool, poorly managed (or, in some instances, any) grazing by livestock can be a significant threat to the maintenance of wetland values.

5.1.2 The effects of livestock grazing in wetlands

Field biologists, hydrologists and soil scientists have observed several conditions in wetlands that are attributable to livestock grazing. Pugging of the soil is one of the most noticeable. Others include the spread of alien weeds and pasture species, low diversity of native plants, and the absence of slow-growing, highly palatable plants. Grazed vegetation types may have a stable species composition but are frequently degraded by livestock grazing when compared to their presettlement state (CFL, 1988). Unpalatable species are also known to expand into areas once covered by palatable species (Chesterfield *et al.* 1984). Livestock also eat and trample rare and threatened wetland plants and degrade the habitat for rare and threatened fauna.

---

[2] Margaret A. Brock, Department of Botany, University of New England, NSW.

Conversely, in some kinds of grazed vegetation, the adjustment to decades of livestock grazing has resulted in the perpetuation of relatively species-rich communities by limiting the dominance by one or a few indigenous or introduced plant species, for example, in the grasslands of New England Tablelands and the seasonal wetlands of the Western Plains grasslands in Victoria. In some wetlands, livestock grazing appears to maintain populations of native annuals which cannot persist under a stand of tall herbaceous perennials (Scarlett[3], pers. comm.).

The scientific literature relating to the effects of grazing on wetlands is presented as a bibliography in the Appendix. These effects have been categorised in relation to soil, hydrology, vegetation and animals. They will vary with

- time of year (the season),
- duration of grazing,
- type of stock,
- stocking rate,
- plant community and the species being grazed, and
- prevailing climatic conditions.

The impacts of livestock grazing will be greatest:

- under high stocking rates,
- when plants (particularly annual species) are in their reproductive phase,
- where grazing is heavy enough to open up the sward and allow the establishment of weed species or reduce its cover value to wildlife,
- when wildlife breed on the ground or in low herbaceous vegetation,
- where the soil is wet; or
- when plant health and vigour is low because of stresses from disease, drought, fire or adverse changes to water regimes.

5.1.3 Livestock grazing and the management of wetlands

In many cases the kinds of changes to wetlands that have been reported to result from grazing are not readily reversible; that is, the removal of grazing cannot necessarily be expected to restore wetlands to their pre-settlement condition.

Moreover, removing grazing from long-grazed wetlands may result in dominance by one or a few species of woody or tall perennial herbaceous species unless:

- the natural hydrological regime prevails;
- there is a local supply of native plant and animal species;
- sources of weeds are not present or limited, or the local environment is unsuitable for weeds and animal pests; and
- there has been no significant increase in soil and water nutrient levels.

Furthermore, it is largely impractical to attempt to restore degraded wetlands to their pre-settlement condition, particularly as in many cases that condition is unknown. Rather, if naturalness is desired, the aim of management should be to minimise the adverse effects of all of the degrading agents and threatening

---

[3] N. Scarlett, Botany Department, LaTrobe University, Victoria.

processes that are operating on the site, and encourage natural processes to continue (Stone 1990). Where this is not practical, it will be necessary to maintain wetlands under opposing artificial influences, using proactive management strategies. This is when livestock grazing may be selected as an appropriate management tool.

5.2 BACKGROUND

5.2.1 The current state of knowledge

Scientific information documenting the effects of grazing on the ecology of Victorian wetlands is limited. In general, current grazing practices within wetlands are a testimony of grazing practices based on tradition rather than scientific evidence, and information on the use of livestock grazing as a management tool tends to be more anecdotal than experimental. Moreover, there are very few examples of livestock grazing being used to manage wetland vegetation for conservation purposes. Research has been conducted on livestock grazing in Victorian alpine wetlands (van Rees and Hutson 1983, Papst *et al.* 1986, van Rees and Holmes 1986) and other studies are under way in NSW (Brock pers. comm.) and in Victoria in the Barmah Forest and at Lake Mokoan.

5.2.2 Current grazing practices in public wetlands in Victoria

The Department of Natural Resources and Environment manages most of the Government-controlled land in the state, and issues annual licences for grazing on many public land parcels. Licences usually specify the type and number of stock, but there are usually no restrictions on the season or duration of grazing. Since a proportion of Victoria is semi-arid or arid, there is a lot of pressure to allow grazing on wetlands.

The primary goal of grazing as currently practised under licence in public wetlands in Victoria is to provide forage and water for stock, and grazing licences have in the past been issued without considering the detrimental effects of grazing. Monitoring of these effects has been minimal.

5.2.3 Grazing practices in private wetlands in Victoria

No quantitative information is available on how or why private wetlands are grazed in Victoria, but anecdotal information suggests they are widely and freely grazed. Some landowners regard wetlands as a valuable source of late summer and autumn forage, and see them as providing additional benefits such as water, shade and shelter for stock. These wetlands are rarely fenced from surrounding grazing land, being managed as part of the available pasture. As wetlands are frequently used as a source of water for stock, the suggestion of fencing a wetland out from grazing may imply that it can no longer be used as a water supply.

Private wetlands are often grazed simply because it is easier and cheaper than not grazing them. That is, the cost of fencing is high and grazing has a perceived management advantage through the reduction of fuel loads and removal of rank vegetation that harbours vermin. Although there is a growing interest by the farming community in the management of private wetlands for conservation, individuals are constrained by their lack of knowledge of wetland needs and of their management options (Oates[4], pers. comm.).

5.3 MANAGING LIVESTOCK GRAZING

5.3.1 General considerations

In some types of wetlands, livestock grazing leads to the degradation of wetland values, and so livestock must be excluded from these wetlands. Grazing may, however, be a useful management tool in certain situations in some wetlands, and the Wetlands Conservation Program for Victoria (Government of Victoria 1988; section 5.1.5) recognised that livestock grazing in wetlands may have a role in:

- managing vegetation,
- controlling pests plants and animals,
- maintaining open water, and
- reducing the fire hazard.

A number of conditions have been identified by local and overseas experts in vegetation management and restoration, and by the authors from the literature, as important in deciding whether to use grazing as a management tool in a particular wetland:

- The plant species to be controlled must be palatable to the stock being grazed.
- Indigenous herbivores where present do not, or (if absent and reintroduction is possible) could not, achieve the same outcomes as managed grazing by livestock.
- The grazing regime must be set by the wetland manager, even if the manager is not the livestock owner.
- The manager should have a good understanding of the effects and limitations of grazing both the site and the particular vegetation communities to be grazed.
- Monitoring of the grazing regime should be feasible.

5.3.2 Roles for livestock grazing in wetlands

The manager should determine the primary management objectives for the wetland before deciding on what role grazing should play. Where managing natural communities is the primary objective, the requirements of the most grazing-sensitive species or communities, including rare or threatened species, should be used to determine if, and how and when these areas are grazed. If there is a multiple-use management objective and grazing is an acceptable use, managers should aim to maintain hydrological and ecological processes and biological productivity. Whatever its role in management, livestock grazing in wetlands needs to be carefully managed and its effects assessed regularly. The role grazing can play in wetland management is considered below.

---

[4] N. Oates, Consultant

Habitat manipulation

Grazing has been shown to slow the spread of invasive, aquatic, emergent plants, maintain or create patchy vegetation such as clumps of shrubs and inter-tussock spaces in herbaceous vegetation, or reduce emergent cover and maintain open water in some instances (Gordon and Duncan 1988). The information on grazing as a habitat management tool in Victorian wetlands is, however, too sparse to identify grazing regimes that will achieve specific management goals. Managers must determine what vegetation structure and species composition are needed to meet a site's management objectives, if grazing will achieve this, and whether livestock compete with indigenous species or otherwise interfere with their productivity.

Fuel reduction

Fuel hazard reduction is a fire management goal. The usefulness of grazing livestock for this purpose depends on the livestock eating plants which would produce fuel. However, stock may prefer species which are not those that produce a fuel hazard (van Rees and Holmes 1986, van Rees and Hutson 1983, CFL 1988), and some fire-promoting species are not eaten at all (Moore[5], pers. comm.). Effective fuel hazard reduction relies on heavy grazing (Burrows 1981, CFL 1988), which is seldom a good management practice because it degrades the soil structure by trampling, makes the soil more erodible, can eliminate annual species, removes habitat and prevents woody plant regeneration. Thus, the amount of grazing desirable for fuel hazard reduction is not compatible with the regimes necessary for habitat manipulation or maintenance of natural values. Other cheap and easily applied techniques are available for fuel hazard reduction.

Control of pest animals

Heavy grazing by livestock will produce a low sward of herbs and grasses in which pest predators (foxes and cats) cannot hide (van der Maarel and Titlyanova 1989), and some wetland fauna show a preference for open situations when they are loafing or, in some cases, nesting. However, a low sward does not provide the habitat diversity (van der Maarel and Titlyanova 1989) usually desired to maintain a high diversity of native wildlife species (Gordon *et al.* in press) and so is not usually suitable where the primary goal of wetland management is to maintain natural values.

Control of pest plants

The effectiveness of grazing as a means of controlling pest plants depends largely on the palatability of the species to be controlled (see 5.1.2 above) and on how preferentially it is grazed by stock. Consideration should also be given to the possibility of spreading pest plants through the faeces of the grazing animal. Where livestock do not graze the target plant preferentially, other more selective methods, such as the careful application of herbicides or mechanical control, should be used.

---

[5] M. Moore, CNR Barmah, Victoria.

5.3.3 Determining the appropriateness of grazing in wetland management

When determining if grazing by livestock is an appropriate wetland management tool, the wetland manager should also consider the following factors.

Present or recent grazing history

If the site has been grazed regularly and is in a condition that meets its management objectives, it may be appropriate to continue grazing the site by maintaining the existing grazing regime. Grazing exclosures would be useful in determining the effects of not grazing.

If the site is in a degraded condition one of the primary actions of management should be to review the current management regime and remove degrading agents and slow degrading processes. In this instance it is appropriate to remove grazing and consider its role in management at some future date.

A wetland that has not been grazed in the past should remain ungrazed where possible.

Palatability of plants

The food preferences of livestock on the site need to be determined so that they graze species whose abundance or structural dominance needs to be reduced, rather than the species whose abundance must be maintained or increased. While this type of investigation can be regarded as specialised, it should be possible to determine some of the grazing preferences through simple observation and the use of grazing exdosure plots.

Grazing-sensitive sites and species

Wetlands containing plant communities and species that cannot tolerate grazing, such as alpine wetlands and salt marsh communities, should not be grazed if their natural values are to be maintained. In other wetlands, annual herbs and ground-dwelling fauna are most at risk from grazing, but grazing can be timed to minimise the risk to sensitive species.

In some instances where grazing could have a role but its application is limited because of =acceptable impacts on some species or communities, grazing only part of the area may be an acceptable option.

Type of livestock

The type of stock to be grazed will be influenced by how and why a wetland is being grazed. Cattle readily enter water to graze emergent macrophytes and will pug wet soils. Cattle can also graze the upper stems of shrubs and lower branches of trees. Sheep are less likely to enter water, cannot graze to the same depth or height as cattle, and are less likely to be placed on wet sites because of the dangers of foot rot and fly strike. Sheep are, however, more likely to graze woody seedlings.

Stocking rate

Excessive stocking has probably been one of the factors most responsible for serious habitat deterioration (CFL 1988), despite the stocking rate being one of the variables that managers have most control over. In wetlands and other areas of unimproved pasture, stocking rates have frequently been based on historical precedents or Australian Bureau of Statistics figures for freehold land. At most it should be the number of stock that can be maintained on the site outside the growing season without supplementary feeding. The available data indicate that it is impractical to determine stocking rates for wetlands *per se.*

Stocking rates should be related to the objectives of grazing, rather than being based on the perceived carrying capacity of the vegetation on the site. The stocking rate should also take account of the likely effects on grazing-sensitive species, the time of year, variations in climatic conditions, and the effects of indigenous and pest grazers.

Most wetlands will carry, either seasonally or permanently, some species of indigenous grazers, such as the Purple Swamphen *(Porphyrio porphyrio),* Black Swan *(Cygnus atratus),* kangaroos and wallabies. Rabbits *(Oryctolagus cuniculus)* are also likely to be present around wetlands. Where livestock grazing has a role in wetland management, the livestock stocking rates will have to allow for the populations and grazing pressure of the indigenous and pest grazers. One sheep is equivalent to between 7 (Myres and Polle 1963, Breckwoldt 1983) and 16 rabbits (Short 1985). Weight for weight, kangaroo species are reported to eat the same amount as a sheep (Breckwoldt 1983, Short 1985). Grazing competition will be heightened when food is in short supply.

The effects of different stocking rates are best determined by specific stocking trials. Supplementary stock feeding should not be needed where grazing has a management role.

Timing of grazing

The timing of grazing is an important consideration when determining a grazing regime for a particular management purpose. It can be timed to minimise damage to particular plant species and vegetation communities and minimise disturbance to wildlife, although a single regime is unlikely to protect all grazing-sensitive species. As a rule of thumb, grazing from mid to late summer up to the autumn break is likely to cause less damage to wetland vegetation than grazing at other times. Grazing should not be undertaken when vegetation communities are under stress, such as during drought or following fire. The following is a broad guide to the timing of grazing to minimise the effects on natural values (Frood, pers. comm.).

Wet grasslands

Avoid grazing in winter and spring, or when wet soil persists. While perennial native grasses and other perennial monocotyledons will tolerate grazing, herbaceous annuals may not, and when soils are wet these communities are easily damaged by pugging, uprooting and heavy grazing.

Herbs and herbaceous wetland and dryland communities

Avoid grazing during the reproductive phase, which should be determined from year to year but would generally include the period July to January.

Woody species and communities

Where regeneration is required, rest from grazing until the growing point of regenerating vegetation is beyond the reach of stock, (for shrubs, until plants are sufficiently large and enough other forage is available so that establishing plants are subject to only light grazing). To avoid damage to woody species, graze only when herbaceous or graminoid forage leyels are sufficient.

Wildlife
Avoid grazing wetlands when they carry significant numbers or species of breeding fauna. Also avoid grazing rank grasslands, reed and rush beds and beaches, and areas frequented by migratory wading birds, during the period August to December.

Soil pugging and reduction in water quality
Avoid soil pugging and detrimental effects on water quality by grazing only over the driest part of the year, from mid summer to the onset of the autumn break. This also coincides with the period when herbaceous annuals and perennials exposed by low water are likely to suffer least damage by grazing or trampling.

Weed control
Grazing before or during flowering may be a useful way of controlling some annual weeds, particularly grasses, but this will be a benefit only where it does not compromise the maintenance of indigenous species.

Managing other degrading agents and processes

Managers need to understand how degrading processes bring about a problem that they think might be relieved by livestock grazing. Salinisation, increases in nutrient levels, or changes in duration of wetting, for example, may encourage the growth and dominance of one or a few species, eg Cumbungi *(Typha* spp.) and Common Reed *(Phragmites australis),* leading to a decline in species diversity and changes in vegetation structure. It is preferable to manage these degrading influences (that is, to treat the cause of the problem and not just the symptom) rather than introduce a grazing regime over which there may be less control or which may have other undesirable affects. Alternatively, it may be necessary to combine grazing with other activities to achieve the best management outcome.

Access to water

If total exclusion of stock from a wetland would deny stock access to water and no other adequate supply exists, other means of supplying water must be investigated. The options include piping water to off-site watering points or fencing off specific areas along the water's edge. If water is piped off-site, the amount of water withdrawn should be minimised so as to maintain, as far as possible, its natural hydrologic regime. A meter may need to be installed to measure withdrawals.

5.4 MONITORING

5.4.1 The role of monitoring in managing grazing

Regular monitoring and documentation is required to improve the current shortfall in scientific information on the effects of grazing in wetlands. Monitoring needs to identify changes over time and determine if grazing has a role in meeting management objectives.

In general, the aim of monitoring grazing (or the exclusion of grazing) in wetlands will be to determine if there are significant changes in the vegetation characteristics that relate to the management objectives. The possible changes include:

- Changes in species composition (the numbers of individuals or population sizes of species), such as:
    - appearance of new species (indigenous, exotic, pest species);
    - return of indigenous species;
    - disappearance of species (indigenous, exotic, pest species);
    - elimination of rare species;
    - elimination of common species; and
    - changes in dominance (visually dominant species becoming visually not dominant or vice versa).
- Changes in vegetation structure (addition or elimination of layers), eg the establishment, re-establishment or loss of trees, shrubs, herbs and ground flora.

In order to make appropriate management decisions concerning livestock grazing in wetlands, monitoring needs to ascertain the quantitative effects of:

- grazing on wetland vegetation, wildlife, soil and water;
- exclusion of grazing on wetland vegetation, wildlife, soil and water;
- grazing in different types of wetlands; and
- different grazing regimes, type of stock, stocking rates and timing of grazing.

5.4.2 Monitoring procedures

Recommended procedures

The recommended procedures for data collection are presented at two levels of detail to simplify decisions regarding monitoring requirements.

Level 1 is less detailed, quicker, and less expensive. It will detect changes from herbaceous to woody plants, shrubs to trees, and annual to perennial herbs, and detect tree decline and changes in vegetation zonation. This level of sampling may be undertaken without extensive botanical field experience.

Level 2 is more time consuming, detailed and expensive, but it is the level most suited to investigate changes in high-value wetlands. It will detect changes in species composition as well as the changes listed for Level 1. This level of sampling requires an experienced field botanist to collect the data and interpret the results.

Timing

Ideally, sampling should be undertaken when plants are flowering or fruiting. This is essential for sampling at Level 2 if a complete species list is required.

Use of exclosures

Exclosure plots (sites fenced to limit all or some types of grazers) provide reference areas that enable comparisons to be made with grazed areas. To account for species that are not abundant, as is common for herbaceous species in some wetland types, grazing exclosures need to be large (eg 50 x 50 metres).

5.4.3 Collecting baseline data

Level 1

Undertake a visual inspection of the site and take general notes. Some information is already available for public and some private wetlands as the minimum data set (MDS) held on the NRE Regional Wetlands Data Base (CNR 1993). If the MDS is not available, record information as set out in the MDS.

At least one permanent photo point should be chosen and permanently marked in each wetland being monitored. An additional photo point should be established in exclosure plots where these are available.

Level 2

In addition to the information collected for Level 1, detail of vegetation composition is required, as follows:

- choose and permanently mark permanent sample sites;
- establish line transects: permanently mark beginning and end (or record exact compass direction and length of lines from permanently marked starting point); choose a line that crosses most or all vegetation types of wetland;
- choose permanent points along transect lines for sample plots, and mark them on the ground or record their distance from a starting point;
- the size of plots should be suitable for type of vegetation being sampled;
- establish plots to sample all vegetation types of every vegetation zone;
- choose and permanently mark photo points for each sample plot;
- for each sample plot:
  - characterise layers, identify tree layers, shrub layers, herb layers, ground layers;
  - characterise according to physiognomic type of primary species (visual dominants the ones you notice on first inspection); and
  - identify primary and other species in each of the layers.

5.4.4 Repeat sampling

Resample annually using the same procedures in the same season as baseline sampling, and using the transects and plots established for baseline sampling. Resampling must be continued for at least five years to collect enough data to determine the nature and direction of any vegetation changes. The presence of some species is influenced by seasonal vagaries that are not completely understood, so repeated sampling over an extended period is the only way to account for these species.

5.4.5 Using monitoring data in decision making

If the trends identified by monitoring are desirable from a management viewpoint, the regime should be maintained and the monitoring continued to ensure that the trends continue to be desirable.

If the trends are undesirable and:

1 grazing is leading to a decline in desirable or rare species or an undesirable loss of vegetation structure, eliminate livestock grazing and monitor to determine when and if grazing should be resumed.

2 grazing is leading to a loss of ground cover and/or desirable woody species are suffering structural damage, modify grazing to reduce stocking density and/or duration and/or timing of grazing if appropriate. Continue monitoring to determine whether the regime is meeting the management needs of grazing and vegetation trends improve.

3 the undesirable effects are peculiar to the type of stock being grazed, change the type of stock, determine new stocking density and/or duration, and modify timing of grazing if appropriate. Continue monitoring to verify desirability of changing stock type and new grazing regime.

4 grazing is inadequate to maintain desired conditions in vegetation or habitat, continue grazing but modify the grazing regime by increasing the stocking density, and/or changing duration and timing of grazing as appropriate. Continue monitoring to verify desirability of new grazing regime.

5 undesirable plant species are appearing or, if already present, their dominance is increasing, remove grazing and take action to limit further infestation, and where appropriate develop an eradication or control program. Monitor to determine if grazing should be reinstated.

5.5 REFERENCES

Breckwoldt, R. 1983. *Wildlife in the home paddock*. Angus and Robertson Australia.

Burrows, N.D. 1981. *Fire hazard reduction by cattle grazing in* Pinus radiata *D. Don plantations in the Blackwood Valley*. Forests Department of Western Australia, Research Paper 67.

CFL, 1988. *Forest Management Guidelines for Wildlife Conservation*. Department of Conservation, Forest and Lands, Melbourne.

Chesterfield, E.A., Loyn, R.H., and Macfarlane, M.A. 1984. Flora and fauna of Barmah State Forest and their management. *For Comm. Vic., Res. Branch Rep. 240.*

CNR, 1993. *PC Regional Wetlands Data Base*. Wetlands Unit, Department of Conservation and Natural Resources, Melbourne.

Gordon, I. and Duncan, P. 1988. Pastures new for conservation. *New Scientist* 117 (1604):54-59.

Myers, K. and Polle, W.E. 1963. A study of the biology of the wild rabbit *Oryctolagus cuniculus* (L) in confined populations: IV. the effects of wild rabbit grazing on sown pasture. *J. Ecol.* 51:435-451.

Papst, W. van Rees, H., and McDougall, K. 1986. Monitoring of the alpine grassland community on the Bogong High Plains, Victoria. In: *Rangelands, A Resource under Siege*. Australian Academy of Science, Canberra: pp. 534-535.

Short, J. 1985. The functional response of kangaroos, sheep and rabbits in an arid grazing system. *J. Appl. Ecol.* 22:435-447.

Stone, C.S. 1990. *Process, stability, and management in wetlands*. Proceedings, Applied Ecology and Conservation Seminar Series III, La Trobe University Wildlife Reserves, Bundoora, Victoria: Oct.-Dec., 1989. La Trobe University.

van der Maarel, E., and Titlyanova, A. 1989. Above-ground and below-ground biomass relations in steppes under different grazing conditions. *Oikos* 56:364-370.

van Rees, H., and Holmes, J.H.G. 1986. The botanical composition of the diet of free-ranging cattle on an alpine range in Australia. *J. Range. Manage.* 39:392-395.

van Rees, H., and Hutson, G.D. 1983. The behaviour of free-ranging cattle on an alpine range in Australia. *J. Range Manage.* 36:740-743.

5.6 APPENDICES

Appendix 5a Bibliography of scientific literature relating to grazing in wetlands

This list is organised by subject and includes the references already listed.

SOILS

Stability

Dahlem, E.A. 1979. The Mahogany Creek watershed—with and without grazing. In: O.B. Cope, (ed). *Proc. Forum-Grazing and Riparian/Stream Ecosystems.* Trout Unlimited, Vienna, Va., USA: pp. 31-34.

Duff, D.A. 1979. Riparian habitat recovery on Big Creek, Rich County, Utah-a summary of 8 years of study. In: O.B. Cope (ed.). *Proc. Forum—Grazing and Riparian/Stream Ecosystems.* Trout Unlimited, Vienna, Virginia, USA pp. 91-92.

Keller, C., Anderson, L. and Tappel, P. 1979. Habitat changes in Summit Creek, Idaho, after fencing the riparian area. In: O.B. Cope (ed.). *Proc. Forum—Grazing and Riparian/Stream Ecosystems.* Trout Unlimited, Vienna, Va., USA pp. 46-52.

Platts, W.S., and Raleigh, R.F. 1984. Impacts of grazing on wetlands and riparian habitat. In: National Research Council and National Academy of Sciences (eds). *Developing Strategies for Rangeland Management.* Westview Press, Boulder: pp. 1105-1117.

Skovlin, J. M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: Nat. Res. Coun./Nat. Academy of Sciences (ed.). *Developing Strategies for Rangeland Management.* Westview Press, Boulder, USA 1001-1102.

Storch, R.L. 1979. Livestock/streamside management programs in eastern Oregon. In O.B. Cope (ed.). *Proc. Forum—Grazing and Riparian/Stream Ecosystems.* Trout Unlimited. Vienna, Va., USA pp. 56-59.

Van Velson, R. 1979. Effects of livestock grazing upon rainbow trout in Otter Creek, Nebraska. In: O.B. Cope (ed.). *Proc. Forum—Grazing and Riparian/Stream Ecosystems.* Trout Unlimited. Vienna,Va., USA pp. 53-55.

Infiltration

Gifford, G.F., and Hawkins, R.H. 1978. Hydrologic impacts of grazing on infiltration: a critical review. *Water Resources Research* 14:305-313.

Skovlin, J. M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: Nat. Res. Coun./Nat. Academy of Sciences (ed.). *Developing Strategies for Rangeland Management.* Westview Press, Boulder, USA 1001-1102.

Weltz, M., and Wood, K. 1986. Short duration grazing in central New Mexico: effects on infiltration rates. *J. Range. Manage.* 39:365-368.

Warren, S.D., Thurow, T.L., Blackburn, W.H., and Garza, N.E. 1986. The influence of livestock trampling under intensive rotation grazing on soil hydrologic characteristics. *J. Range Manage.* 39:491-495.

Sediment production

Skovlin, J. M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: Nat. Res. Coun./Nat. Academy of Sciences (ed.). *Developing Strategies for Rangeland Management.* Westview Press, Boulder, USA 1001-1102.

Warren, S.D., Thurow, T.L., Blackburn, W.H., and Garza, N.E. 1986. The influence of livestock trampling under intensive rotation grazing on soil hydrologic characteristics. *J. Range Manage.* 39:491-495.

Structure

Buckhouse, J.C., Skovlin, J.M., and Knight, R.W. 1981. Streambank erosion and ungulate grazing relationships. *I. Range Manage.* 34:339-340.

Skovlin, J. M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: Nat. Res. Coun./Nat. Academy of Sciences (ed.). *Developing Strategies for Rangeland Management* . Westview Press, Boulder, USA 1001-1102.

Warren, S.D., Thurow, T.L., Blackburn, W.H., and Garza, N.E. 1986. The influence of livestock trampling under intensive rotation grazing on soil hydrologic characteristics. *J. Range Manage.* 39:491-495.

VEGETATION

Cover and area

Biddiscombe 1953. Cited in: Arnold, A. H. 1977. *A review of the effects of grazing on natural ecosystems in Victoria.* Department of Crown Lands and Survey, Melbourne.

Costin, A.B. 1970. Cited in: Arnold, A. H. 1977. *A review of the effects of grazing on natural ecosystems in Victoria.* Department of Crown Lands and Survey, Melbourne.

Dahlem, E.A. 1979. The Mahogany Creek watershed-with and without grazing. In: O. B. Cope, (ed.). *Proc. Forum—Grazing and Riparian/Stream Ecosystems.* Trout Unlimited, Vienna,Va., USA: pp. 31-34.

Duff, D.A. 1979. Riparian habitat recovery on Big Creek, Rich County, Utah-a summary of 8 years of study. In: O.B. Cope (ed.). *Proc. Forum—Grazing and Riparian/Stream Ecosystems.* Trout Unlimited, Vienna, Virginia, USA pp. 91-92.

Keller, C., Anderson, L. and Tappel, P. 1979. Habitat changes in Summit Creek, Idaho, after fencing the riparian area. In: O.B. Cope (ed.). *Proc. Forum — Grazing and Riparian/Stream Ecosystems.* Trout Unlimited, Vienna,Va., USA pp. 46-52.

McDougall, K.L. 1989. The Effect of Excluding Cattle from a Mossbed on the Bogong High Plains, Victoria. *Tech. Report Series No.* 95. National Parks and Wildlife Division, Department of Conservation, Forests and Lands, Victoria.

Platts, W.S. 1979. Livestock grazing and riparian/stream ecosystems—an overview. In: O.B. Cope (ed.). *Proceedings of the Forum—Grazing and Riparian/Stream Ecosystems Conference.* Trout Unlimited, Vienna,Va., USA: pp. 39-45.

Skovlin, J. M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: Nat. Res. Coun./Nat. Academy of Sciences (ed.).

Developing Strategies for Rangeland Management. Westview Press, Boulder, USA 1001-1102.

van Rees, H., and Holmes, J.H.G. 1986. The botanical composition of the diet of free-ranging cattle on an alpine range in Australia. *J. Range Manage.* 39:392-395.

van Rees, H., and Hutson, G.D. 1983. The behaviour of free-ranging cattle on an alpine range in Australia. *J. Range Manage.* 36:740-743.

Productivity

Jefferies R.J., Bazely, D.R., and Cargil, S.M. 1986. Effects of grazing on tundra vegetation - a positive-feedback model. In: *Rangelands: A Resource Under Siege.* Australian Academy of Science, Canberra, p. 50.

Reimold, R.J., Linthurst, R.A. and Wolf, P.A. 1975. Effects of grazing on a salt marsh. *Biol. Conserv.* 8:105-125.

Debris/litter

Jefferies R.J., Bazely, D.R., and Cargil, S.M. 1986. Effects of grazing on tundra vegetation - a positive-feedback model. In: *Rangelands: A Resource Under Siege.* Australian Academy of Science, Canberra, p. 50.

Reimold, R.J., Linthurst, R.A. and Wolf, P.A. 1975. Effects of grazing on a salt marsh. *Biol. Conserv.* 8:105-125.

Species **composition and diversity**

Bulow-Olsen, A. 1980. Changes in the species composition in an area dominated by *Deschampsia flexuosa* (L.) Trin. as a result of cattle grazing. *Biol. Conserv.* 18:257-270.

Chesterfield, E.A., Loyn, R.H., and Macfarlane, M.A. 1984. Flora and fauna of Barmah State Forest and their management. *For. Comm. Vic., Res. Branch Rep. 240.*

Jefferies R.J., Bazely, D.R., and Cargil, S.M. 1986. Effects of grazing on tundra vegetation-a positive-feedback model. In: Rangelands: *A Resource Under Siege.* Australian Academy of Science, Canberra, p. 50.

Lodge, G.M., and Whalley, R.D.B. 1985. The manipulation of species composition of natural pastures by grazing management on the northern slopes of New South Wales. *Aust. Rangel. J.* 7:6-16.

Lunt, I.D. 1990. Species-area curves and growth-form spectra for some herb-rich woodlands in western Victoria, Australia. *Aust. J. Ecol.* 15:155-161.

McIntyre, S., Ladiges, P.Y., and Adams, G. 1988. Plant species-richness and invasion by exotics in relation to disturbance of wetland communities on the Riverine Plain, NSW. *Aust. J. Ecol.* 13.

Ranwell, D.S. 1961. Spartina salt marshes in southern England. I. The effects of sheep grazing at the upper limits of Spartina marsh in Bridgewater Bay. *J. Ecol.* 49:325-340.

Skovlin, J. M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: Nat. Res. Coun./Nat. Academy of Sciences (ed.). *Developing Strategies for Rangeland Management.* Westview Press, Boulder, USA, pp 1001-1102.

Tyler J.P. 1987. Vegetation surveys near Lake MacLeod. *Kingia* 1:49-74.

Regeneration

Bakker, J. P., De Bie, S., Dallinga, J. H., Tjaden, P., and De Vries, Y. 1983. Sheep grazing as a management tool for heathland conservation and regeneration in the Netherlands. *I. Appl. Ecol.* 20:541-560.

Costin A. B. 1958. The grazing factor and the maintenance of catchment values in the Australian Alps. *Division of Plant Industries Technical Paper No. 10.* CSIRO, Canberra.

Gibson, C.W.D., Watt, T.A., and Brown, V. K. 1987. The use of sheep grazing to recreate species-rich grassland from abandoned arable land. *Biol. Conserv.* 42:165-183.

Keller, C., Anderson, L. and Tappel, P. 1979. Habitat changes in Summit Creek, Idaho, after fencing the riparian area. In: O.B. Cope (ed.). *Proc. Forum—Grazing and Riparian/Stream Ecosystems.* Trout Unlimited, Vienna,Va., USA pp. 46-52.

McIvor, J.G., and Gardener, C.J. 1990. Soil and vegetation characteristics of dry tropical rangelands for predicting pasture regeneration in exclosures. *Proc. Ecol. Soc. Aust.* 16:273-277.

Middleton, B. A. 1990. Effect of water depth and clipping frequency on the growth and survival of four wetland plant species. *Aquatic Biology* 37:189-96.

Ranwell, D.S. 1961. Spartina salt marshes in southern England. I. The effects of sheep grazing at the upper limits of Spartina marsh in Bridgewater Bay. *I. Ecol.* 49:325-340.

Reimold, R.J., Linthurst, R.A. and Wolf, P.A. 1975. Effects of grazing on a salt marsh. *Biol. Conserv.* 8:105-125.

Skovlin, J. M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: Nat. Res. Coun./Nat. Academy of Sciences (ed.). *Developing Strategies for Rangeland Management.* Westview Press, Boulder, USA 1001-1102.

Van Velson, R. 1979. Effects of livestock grazing upon rainbow trout in Otter Creek, Nebraska. In: O.B. Cope (ed.). *Proc. Forum—Grazing and Riparian/Stream Ecosystems.* Trout Unlimited, Vienna,Va., USA pp. 53-55.

Structure

Keller, C., Anderson, L. and Tappel, P. 1979. Habitat changes in Summit Creek, Idaho, after fencing the riparian area. In: O.B. Cope (ed.). *Proc. Forum—Grazing and Riparian/Stream Ecosystems.* Trout Unlimited, Vienna,Va., USA pp. 46-52.

Loft, E.R. Menke, J.W. and Kie, J.G. 1986. Interaction of cattle and deer on mountain rangeland. *Calif. Agric.* (Jan-Feb) pp. 6-9.

Platts, W.S. 1978. Livestock interactions with fish and aquatic environments: problems in evaluation. Transcripts of the 43rd North American Wildlife and Natural Resources Conference: pp. 498-505.

Putman, R.J., Edwards, P.J., Mann, J.C.E., How, R.C., and Hill, S.D. 1989. Vegetational and faunal changes in an area of heavily grazed woodland following relief of grazing. *Biol. Conserv.* 47:13-32.

Storch, R.L. 1979. Livestock/streamside management programs in eastern Oregon. O.B. Cope (ed.). *Proc. Forum— Grazing and Riparian/Stream Ecosystems.* Trout Unlimited, Vienna,Va., USA pp. 56-59.

Taylor, D.M. 1986. Effects of cattle grazing on passerine birds nesting in riparian habitat. *J. Range Manage.* 39:254-258.

Skovlin, J. M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: Nat. Res. Coun./Nat. Academy of Sciences (ed.). *Developing Strategies for Rangeland Management.* Westview Press, Boulder, USA 1001-1102.

van Velson, R. 1979. Effects of livestock grazing upon rainbow trout in Otter Creek, Nebraska. In: O.B. Cope (ed.). *Proc. Forum-Grazing and Riparian/Stream Ecosystems.* Trout Unlimited, Vienna,Va., USA pp. 53-55.

Williams, O.B. 1968. Studies in the ecology of the Riverine Plain. IV. Basal area and density changes of *Danthonia caespitosa* Gaudich. in a natural pasture grazed by sheep. *Aust. J. Bot.* 16:565-578.

Williams, O. B. 1969. Studies in the ecology of the Riverine Plain. V. Plant density response of species in *a Danthonia caespitosa* grassland to 16 years of grazing by merino sheep. *Aust. J. Bot.* 17:255-268.

Dynamics

Barker, S. 1979. Shrub population dynamics under grazing — within paddock studies. In: *Studies of the Australian Arid Zone, Vol. IV.* pp. 83-106.

Bassett, P.A. 1980. Some effects of grazing on vegetation dynamics in the Camargue, France. *Vegetation* 43:173-184.

Crisp, M.D. 1978. Demography and survival under grazing of three Australian semi-desert shrubs. *Oikos* 30:520-528.

Day, T.A. and Detling, J.K. 1990. Grassland patch dynamics and herbivore grazing preference following urine deposition. *Ecology* 71:180-188.

Graetz, R.D. 1980. The influence of grazing by cattle and sheep on the population dynamics of bladder saltbush *(A triplex vesicaria)* and white top *(Danthonia caespitosa). Aust. Rangel. J.* 2:208-213.

Jefferies R.J., Bazely, D.R., and Cargil, S.M. 1986. Effects of grazing on tundra vegetation — a positive-feedback model. In: Australian Academy of Science (ed.). *Rangelands: A Resource Under Siege.* Canberra, p. 50.

Lay, B. 1979. Shrub population dynamics under grazing: a long term study. In: R.D. Graetz and K.M.W. Howes (eds). *Studies of the Australian Arid Zone, Vol. IV.* CSIRO, Melbourne.

Papst, W. van Rees, H., and McDougall, K. 1986. Monitoring of the alpine grassland community on the Bogong High Plains, Victoria. In: Australian Academy of Science (ed.). *Rangelands, A Resource under Siege.* Canberra, pp. 534-535.

Ranwell, D.S. 1961. *Spartina* salt marshes in southern England. I. The effects of sheep grazing at the upper limits of Spartina marsh in Bridgewater Bay. *J. Ecol.* 49:325-340.

Wimbush, D.J., and Costin, A.B. 1979. Trends in vegetation at Kosciusko. III. Alpine range transects, 1959-1978. *Aust. J. Bot.* 27:833-871.

Use by livestock

ACIL Australia Pty. Ltd 1984. *A Study of Forest Grazing in the Murray Valley.* Report to the Land Conservation Council. Collingwood, Victoria.

Bakker, J.P. 1978. Changes in a salt-marsh vegetation as a result of grazing and mowing-a five-year study of permanent plots. *Vegetation* 38:77-87.

Costin, A.B. 1970. Cited in: Arnold, A. H. 1977. A review of the effects of grazing on natural ecosystems in Victoria. Department of Crown Lands and Survey, Melbourne.

Department of Crown Lands and Survey 1977. Grazing on Crown Land. Bull. 5 *VGPO.* Melbourne.

Middleton, B. A. 1990. Effect of water depth and clipping frequency on the growth and survival of four wetland plant species. Aquatic Biology 37:189-96.

Murray Valley Management Review 1987. Grazing. Discussion Paper *2.8.* Department of Environment and Planning. Adelaide.

Platts, W.S. 1979. Livestock grazing and riparian/stream ecosystems—an overview. In: O.B. Cope (ed.). Proceedings of the Forum—Grazing and Riparian/Stream Ecosystems Conference. Trout Unlimited, Vienna,Va., USA: pp. 39-45.

Thomas, J.W., Maser, C., and Rodiek, J.E. 1979. Riparian zones in managed rangelands-their importance to wildlife. In: O.B. Cope (ed.). Op. cit. Trout Unlimited, Vienna,Va., USA pp. 21-31.

van Rees, H., Papst, W.A., McDougall, K. and Boston, R.C. 1985. Trends in vegetation cover in the grassland community on the Bogong High Plains, Victoria. Aust. Rangel. *J.* 7:93-98.

Wilson, A.D. 1976. Comparison of sheep and cattle grazing on a semiarid grassland. Aust. I. *Agric.* Res. 27:155-162.

Wilson, A.D. 1990. The effect of grazing on Australian ecosystems. Proc. *Ecol.* Soc. Aust. 16:235-244.

Water

Stream channel characteristics

Dahlem, E.A. 1979. The Mahogany Creek watershed-with and without grazing. In: O. B. Cope, (ed.). Proc. Forum—Grazing and Riparian/Stream Ecosystems. Trout Unlimited, Vienna,Va., USA: pp. 31-34.

Duff, D.A. 1979. Riparian habitat recovery on Big Creek, Rich County, Utah-a summary of 8 years of study. In: O.B. Cope (ed.). Proc. Forum—Grazing and Riparian/Stream Ecosystems. Trout Unlimited. Vienna, Virginia, USA pp. 91-92.

Keller, C., Anderson, L. and Tappel, P. 1979. Habitat changes in Summit Creek, Idaho, after fencing the riparian area. In: O.B. Cope (ed.). Op. cit.. Trout Unlimited, Vienna,Va., USA pp. 46-52.

Platts, W.S. 1979. Livestock grazing and riparian/stream ecosystems—an overview. In: O.B. Cope (ed.). Proceedings of the Forum—Grazing and Riparian/Stream Ecosystems Conference. Trout Unlimited, Vienna,Va., USA: pp. 39-45.

van Velson, R. 1979. Effects of livestock grazing upon rainbow trout in Otter Creek, Nebraska. In: O.B. Cope (ed.). Op. cit. Trout Unlimited. Vienna,Va., USA pp. 53-55.

Turbidity

Lusby 1970. Cited in: Platts, W.S. 1978. Livestock interactions with fish and aquatic environments: problems in evaluation. Transcripts of the *43rd* North American Wildlife and Natural Resources Conference: pp. 498-505.

Platts, W.S. 1978. Livestock interactions with fish and aquatic environments: problems in evaluation. *Transcripts of the 43rd North American Wildlife and Natural Resources Conference:* pp. 498-505.

Platts, W.S. 1979. Livestock grazing and riparian/stream ecosystems—an overview. In: O.B. Cope (ed.). *Op. cit.* Trout Unlimited, Vienna,Va., USA pp. 39-45.

Skovlin, J. M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: Nat. Res. Coun./Nat. Academy of Sciences (ed.). *Developing Strategies for Rangeland Management.* Westview Press, Boulder, USA 1001-1102.

van **Velson, R. 1979.** Effects of livestock grazing upon rainbow trout in Otter Creek, Nebraska. In: O.B. Cope (ed.). *Proc. Forum—Grazing and Riparian/Stream Ecosystems.* Trout Unlimited. Vienna,Va., USA pp. 53-55.

Detritus

Platts, W.S. 1979. Livestock grazing and riparian/stream ecosystems—an overview. In: O.B. Cope (ed.). Op. *cit.* Trout Unlimited, Vienna,Va., USA: pp. 39-45.

Coliform counts

Duff, D.A. 1979. Riparian habitat recovery on Big Creek, Rich County, Utah-a summary of 8 years of study. In: O.B. Cope (ed.). *Proc. Forum—Grazing and Riparian/Stream Ecosystems.* Trout Unlimited, Vienna, Virginia, USA pp. 91-92.

Reimold, R.J., Linthurst, R.A. and Wolf, P.A. 1975. Effects of grazing on a salt marsh. *Biol. Conserv.* 8:105-125.

Skovlin, J. M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: Nat. Res. Coun./Nat. Academy of Sciences (ed.). *Developing Strategies for Rangeland Management.* Westview Press, Boulder, USA 1001-1102.

van **Velson, R. 1979.** Effects of livestock grazing upon rainbow trout in Otter Creek, Nebraska. In: O.B. Cope (ed.). *Op. cit.* Trout Unlimited, Vienna,Va., USA pp. 53-55.

Water quality

Johnson, S.R. Gary, H.L., and Ponce, S.L. 1978. Range cattle impacts on stream water quality in the Colorado Front Range. *Res. Note RM-359.* US Forest Service Rocky Mountain Forest and Range Experiment Station.

Temperature

Platts, W.S. 1979. Livestock grazing and riparian/stream ecosystems—an overview. In: O.B. Cope (ed.). *Op. cit* Trout Unlimited, Vienna,Va., USA: pp. 39-45.

Skovlin, J. M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: Nat. Res. Coun./Nat. Academy of Sciences (ed.). *Developing Strategies for Rangeland Management.* Westview Press, Boulder, USA 1001-1102.

Storch, R.L. 1979. Livestock/streamside management programs in eastern Oregon. In O.B. Cope (ed.). *Op. cit.* Trout Unlimited, Vienna,Va., USA pp. 56-59.

Nutrients

Williams, O.B. 1968. That uneasy state between animal and plant in the manipulated situation. *Proc. Ecol. Soc. Australia* 3:167-174.

Water quantity

Costin A. B. 1958. The grazing factor and the maintenance of catchment values in the Australian Alps. *Division of Plant Industries Technical Paper No. 10*. CSIRO, Canberra.

McDougall, K.L. 1989. The effect of excluding cattle from a mossbed on the Bogong High Plains, Victoria. *Tech. Report Series No.* 95. National Parks and Wildlife Division, Department of Conservation, Forests and Lands, Victoria.

van Velson, R. 1979. Effects of livestock grazing upon rainbow trout in Otter Creek, Nebraska. In: O.B. Cope (ed.). *Op. cit.* Trout Unlimited, Vienna,Va., USA pp. 53-55.

FAUNA

Fish habitat

Keller, C., Anderson, L. and Tappel, P. 1979. Habitat changes in Summit Creek, Idaho, after fencing the riparian area. In: O.B. Cope (ed.). *Proc. Forum—Grazing and Riparian/Stream Ecosystems*. Trout Unlimited, Vienna,Va., USA pp. 46-52.

Platts, W.S. 1979. Livestock grazing and riparian/stream ecosystems—an overview. In: O.B. Cope (ed.). *Op. cit.* Trout Unlimited, Vienna,Va., USA: pp. 39-45.

Platts, W.S. 1982. Livestock and riparian-fishery interactions: what are the facts? *Transcripts of the 47th North American Wildlife Conference:* pp. 507-515.

Skovlin, J. M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: Nat. Res. Coun./Nat. Academy of Sciences (ed.). *Developing Strategies for Rangeland Management.* Westview Press, Boulder, USA 1001-1102.

van Velson, R. 1979. Effects of livestock grazing upon rainbow trout in Otter Creek, Nebraska. In: O.B. Cope (ed.). *Op. cit.* Trout Unlimited, Vienna,Va., USA pp. 53-55.

Fish abundance

Gunderson, D.R. 1968. Floodplain use related to stream morphology and fish populations. *J. Wildl. Manage.* 32:507-514.

Skovlin, J. M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: Nat. Res. Coun./Nat. Academy of Sciences (ed.). *Developing Strategies for Rangeland Management.* Westview Press, Boulder, USA 1001-1102.

Fish reproduction

Keller, C., Anderson, L. and Tappel, P. 1979. Habitat changes in Summit Creek, Idaho, after fencing the riparian area. In: O.B. Cope (ed.). *Op. cit.* Trout Unlimited, Vienna,Va., USA pp. 46-52.

van Velson, R. 1979. Effects of livestock grazing upon rainbow trout in Otter Creek, Nebraska. In: O.B. Cope (ed.). *Op. cit.* Trout Unlimited, Vienna,Va., USA pp. 53-55.

Fish species composition

Platts, W.S. 1979. Livestock grazing and riparian/stream ecosystems—an overview. In: O.B. Cope (ed.).*Op. cit* Trout Unlimited, Vienna,Va., USA pp. 39-45.

Bird species abundance

de Jong, H. 1977. Experiences with the man-made meadow bird reserve 'Kievitslanden' in Flevoland (The Netherlands). *Biol. Conserv.* 12:13-31.

Skovlin, J. M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: Nat. Res. Coun./Nat. Academy of Sciences (ed.). *Developing Strategies for Rangeland Management.* Westview Press, Boulder, USA 1001-1102.

Taylor, D.M. 1986. Effects of cattle grazing on passerine birds nesting in riparian habitat. J. *Range Manage.* 39:254-258.

Bird species reproduction

Skovlin, J. M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: Nat. Res. Coun./Nat. Academy of Sciences (ed.). *Developing Strategies for Rangeland Management.* Westview Press, Boulder, USA 1001-1102.

Bird species composition

de Jong, H. 1977. Experiences with the man-made meadow bird reserve "Kievitslanden" in Flevoland (The Netherlands). *Biol. Conserv.* 12:13-31.

Skovlin, J. M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: Nat. Res. Coun./Nat. Academy of Sciences (ed.). *Developing Strategies for Rangeland Management.* Westview Press, Boulder, USA 1001-1102.

Taylor, D.M. 1986. Effects of cattle grazing on passerine birds nesting in riparian habitat. *J. Range Manage.* 39:254-258.

Bird species diversity

Duff, D.A. 1979. Riparian habitat recovery on Big Creek, Rich County, Utah-a summary of 8 years of study. In: O.B. Cope (ed.). *Proc. Forum—Grazing and Riparian/Stream Ecosystems.* Trout Unlimited, Vienna, Virginia, USA pp. 91-92.

Management of bird habitat

de Jong, H. 1977. Experiences with the man-made meadow bird reserve "Kievitslanden" in Flevoland (The Netherlands). *Biol. Conserv.* 12:13-31.

Duncan, P., and D'Herbes, J.M. 1982. The use of domestic herbivores in the management of wetlands for waterbirds in the Camargue, France. In: D.A. Scott (ed.). *Management of Wetlands and their Birds.* Slimbridge, International Waterfowl Research Bureau, pp. 51-67.

Green, R.E. 1986. The management of lowland wet grassland for breeding waders. *Internal Report for The Royal Society for the Protection of Birds.*

Ruyle, G.B., Menke, J.W., and Lancaster, D.L. 1980. Delayed grazing may improve upland waterfowl habitat. *Calif. Agric.* Nov.-Dec., 29-31.

Mammal species diversity

Duff, D.A. 1979. Riparian habitat recovery on Big Creek, Rich County, Utah-a summary of 8 years of study. In: O.B. Cope (ed.). *Proc. Forum—Grazing and Riparian/Stream Ecosystems.* Trout Unlimited. Vienna,Virginia, USA pp. 91-92.

Putman, R.J., Edwards, P.J., Mann, J.C.E., How, R.C., and Hill, S.D. 1989. Vegetational and faunal changes in an area of heavily grazed woodland following relief of grazing. *Biol. Conserv.* 47:13-32.

Skovlin, J. M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: Nat. Res. Coun./Nat. Academy of Sciences (ed.).

Developing Strategies for Rangeland Management. Westview Press, Boulder, USA 1001-1102.

Mammal reproduction/productivity

Platts, W.S. 1979. Livestock grazing and riparian/stream ecosystems—an overview. In: O.B. Cope (ed.). *Proceedings of the Forum—Grazing and Riparian/Stream Ecosystems Conference.* Trout Unlimited, Vienna,Va., USA: pp. 39-45.

Mammal abundance

Skovlin, J. M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: Nat. Res. Coun./Nat. Academy of Sciences (ed.). *Developing Strategies for Rangeland Management.* Westview Press, Boulder, USA 1001-1102.

Terrestrial invertebrate abundance

Reimold, R.J., Linthurst, R.A. and Wolf, P.A. 1975. Effects of grazing on a salt marsh. *Biol. Conserv.* 8:105-125.

Skovlin, J. M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: Nat. Res. Coun./Nat. Academy of Sciences (ed.). *Developing Strategies for Rangeland Management.* Westview Press, Boulder, USA 1001-1102.

Aquatic invertebrate abundance

Keller, C., Anderson, L. and Tappel, P. 1979. Habitat changes in Summit Creek, Idaho, after fencing the riparian area. In: O.B. Cope (ed.). *Proc. Forum—Grazing and Riparian/Stream Ecosystems.* Trout Unlimited, Vienna,Va., USA pp. 46-52.

Platts, W.S. 1979. Livestock grazing and riparian/stream ecosystems—an overview. In: O.B. Cope (ed.). *Proceedings of the Forum—Grazing and Riparian/Stream Ecosystems Conference.* Trout Unlimited, Vienna,Va., USA: pp. 39-45.

van Velson, R. 1979. Effects of livestock grazing upon rainbow trout in Otter Creek, Nebraska. In: O.B. Cope (ed.). *Proc. Forum—Grazing and Riparian/Stream Ecosystems.* Trout Unlimited. Vienna,Va., USA pp. 53-55.

WETLAND TYPE

Alpine

Costin A.B. 1958. The grazing factor and the maintenance of catchment values in the Australian Alps. *Division of Plant Industries Technical Paper No. 10* CSIRO. Canberra.

Costin, A.B. 1970. Cited in: Arnold, A.H. 1977. *A Review of The Effects of* Grazing *on Natural Ecosystems in Victoria.* Department of Crown Lands and Survey.,

McDougall, K.L. 1989. The Effect of Excluding Cattle from a Mossbed on the Bogong High Plains, Victoria. *Tech. Report Series No. 95, National Parks and Wildlife Division.* Department of Conservation, Forests and Lands, Victoria.

Wimbush, D.J., and Costin, A.B. 1979. Trends in vegetation at Kosciusko. III. Alpine range transects, 1959-1978. *Aust. J. Bot.* 27:833-871.

Heath

Grant, S.A., Bolton, G.R., and Towell, L. 1985. The response of blanket bog vegetation to controlled grazing by hell sheep. *J. Appl. Ecol.* 22:739-751.

Williams, R.J. 1990. Cattle grazing within subalpine heathland and grassland communities on the Bogong High Plains: disturbance, regeneration and the shrub-grass balance. *Proc. Ecol. Soc. Aust.* 16:255-265.

Salt marsh

Bakker, J.P. 1978. Changes in a salt-marsh vegetation as a result of grazing and mowing - a five-year study of permanent plots. *Vegetation* 38:77-87.

Bakker, J.P. 1985. The impact of grazing on plant communities, plant populations and soil conditions on salt marshes. *Vegetation* 62:391-398.

Bakker, J. P., Dijkstra, M., and Russchen, P.T. 1985. Dispersal, germination and early establishment of halophytes and glycophytes on a grazed and abandoned salt-marsh gradient. *New Phytol.* 101:291-308.

Bakker, J. P. and Ruyter, J.C. 1981. Effects of five years of grazing on a salt-marsh vegetation. A study with sequential mapping. *Vegetation* 44:81-100.

Daiber, F.C. 1974. Salt marsh plants and future coastal salt marshes in relation to animals. In: R.J. Reimold and W.H. Queen (eds). *Ecology of Halophytes*. New York, Academic Press: pp. 475-510.

Hik, D.S., and Jefferies, R.L. 1990. Increases in the net above-ground primary production of a salt-marsh forage grass: a test of the predictions of the herbivore-optimization model. *J. Ecol.* 78:180-195.

Jefferies R.J., Bazely, D.R., and Cargil, S.M. 1986. Effects of grazing on tundra vegetation-a positive-feedback model. In: Australian Academy of Science (ed.). *Rangelands: A Resource Under Siege*. Canberra, p. 50.

Ranwell, D.S. 1961. Spartina salt marshes in southern England. I. The effects of sheep grazing at the upper limits of Spartina marsh in Bridgwater Bay. *J. Ecol.* 49:325-340.

Reimold, R.J., Linthurst, R.A. and Wolf, P.A. 1975. Effects of grazing on a salt marsh. *Biol. Conserv.* 8:105-125.

Williams, G., and Hall, M. 1987. The loss of coastal grazing marshes in South and East England, with special reference to East Sussex, England. *Biol. Conserv.* 39:243-253.

Floodplain

Chesterfield, E.A. 1986. Changes in the vegetation of the river red gum forest at Barmah, Victoria. *Aust. For.* 49:4-15.

Chesterfield, E.A., Loyn, R.H., and Macfarlane, M.A. 1984. Flora and fauna of Barmah State Forest and their management. *For Comm. Vic., Res. Rep. 240.*

McIntyre, S., Ladiges, P.Y., and Adams, G. 1988. Plant species-richness and invasion by exotics in relation to disturbance of wetland communities on the Riverine Plain, NSW. *Aust. J. Ecol.* 13.

Margules and Partners, Smith, P., Smith, J., and Department of Conservation Forests and Lands 1990. *River Murray Riparian Vegetation Study.* Murray-Darling Basin Commission.

MISCELLANEOUS

Ball, M.E. 1974. Floristic changes in grasslands and heaths on the Isle of Rhum after a reduction or exclusion of grazing. *J. Envir. Mgmt.* 2:299-381.

Beckmann, R. 1991. Kangaroos on the farm. *Ecos* 66, Summer, CSIRO.

Bonham, C.D. 1989. *Measurements for Terrestrial Vegetation.* New York, Wiley.

Chew, R.M. 1974. Consumers as regulators of ecosystems: an alternative to energetics. *Ohio J. Sci.* 74:359-369.

Cope, O.B. (ed.) 1979. *Proceedings of the Forum on Grazing and Riparian/Stream Ecosystems.* Trout Unlimited, Vienna,Va. USA

Duncan, A. 1986. *Management Plan for Tour du Valat-Petit Badon, Camargue, France, 01.09.1986-31.08.1991, Vol. II.* Station Biologique de la Tour du Valat, Le Sambuc, Arles, France.

Forests Commission of Victoria 1959. *Forestry Technical Papers* 1. FCV, Melbourne.

Gordon, I.J., Duncan, P., Grillas, P., and Lecomte, T. in press. Conservation of the biological richness of European wetlands: the role of domestic ungulates. *Bulletin d'Ecologie.*

Noy-Meir, I. 1975. Stability of grazing systems: an application of predator—prey graphs. *I. Ecol.* 63:459-481.

Owen-Smith, N. 1989. Megafaunal extinctions: the conservation message from 11,000 B.P. *Conservation Biol.* 3:405-412.

Platts, W.S. 1981. Effects of sheep grazing on a riparian-stream environment. *Res. Note INT-307.* Intermountain Forest and Range Experiment Station, US Forest Service.

Platts, W.S., and Raleigh, R.F. 1984. Impacts of grazing on wetlands and riparian habitat. In: National Research Council and National Academy of Sciences (eds). *Developing Strategies for Rangeland Management.* Westview Press, Boulder: pp. 1105-1117.

Platts, W.S., and Rinne, J.N. 1985. Riparian and stream enhancement management and research in the Rocky Mountains. *North Am J.Fisheries Manage.* 5:115-125.

Pressey, R.L. 1988. *The Murray Wetlands in South Australia: Management Considerations and Research Needs.* Murray Valley Management Review, Background Paper. Murray Valley Management Review.

Thalen, D.C.P. 1984. Large mammals as tools in the conservation of diverse habitats. *Acta Zool. Fenn.* 172:159-163.

Warren, S.D., Thurow, T.L., Blackburn, W.H., and Garza, N.E. 1986. The influence of livestock trampling under intensive rotation grazing on soil hydrologic characteristics. *J. Range Manage.* 39:491-495.

Whalley, R.D.B., and Lodge, G.M. 1990. *Grazing management and animal production on rangelands on the northern slopes and tablelands of New South Wales.* Poster, Aust. Rangeland Soc. Biennial Conference, Carnarvon, WA, Sept., 1990.

Williams, O.B. 1970. *Longevity and survival of some dietary constituents in a natural semi-arid grassland grazed by sheep.* Proc. 11th International Grassland Congress, Brisbane, pp. 85-88.

6 FIRE MANAGEMENT

6.1 INTRODUCTION

Fire has been reported to be second only to hydrology and hydrological change as an influence on wetland vegetation (Gore 1983). The effects of fire in wetlands include the destruction of peat beds, changes in vegetation composition, reduction of the organic surface layer, exposure of roots and rhizomes, increased sedimentation and short-term increases in water temperature resulting from increased insolation (Gore 1983, Pressey and Harris 1988). Studies by Faulkner and de la Cruz (1982) indicate that fire may stimulate primary production in wetlands, reduce the levels of toxic allelochemicals and sustain rhizomatous perennials. While fire is reported to enhance wetland fauna habitat for some groups (eg waterfowl), the influence of fire on the productivity of wetland fauna is undetermined (Smith and Kadlec 1984). Fire can destroy nesting sites.

The Wetlands Conservation Program for Victoria (WCP) (CFL et *al.* 1988) identified fire as a potentially threatening process to wetlands in Victoria:

> Wildfires and fuel reduction burning can reduce wetland values. In particular, wetlands need to be protected from fire.. .Fire can destroy food, cover and nest sites, and can occur even in emergent vegetation when a wetland contains water (WCP 4.14:15).

A partial inventory in publicly-owned wetlands across Victoria has indicated that fires are common in these wetlands, that these fires are often small and are frequently associated with recreational use. Wetlands on private land may be subject to a more frequent fire regime, however, as land owners use fire to clear wetland vegetation or manage it for grazing.

The following is drawn from the available scientific literature. It is not based on any primary research or data collection. Much of the information that is readily available discusses the application of fire to achieve a stated management objective, such as the manipulation of vegetation to enhance habitat for certain wildlife groups, or improve its palatability for grazing. The bulk of the literature deals primarily with northern hemisphere wetlands as very little of the Australian fire literature relates to wetland or associated habitats. Some data and anecdotal information have been received from wetland managers and fire protection staff in the Department of Natural Resources and Environment (NRE), and some are based on the experiences and observations of the author.

6.2 THE ROLE OF FIRE IN WETLAND ECOLOGY

Wetlands in general are described by Odum (1967) as being pulse stable ecosystems. This means that their stability relies on alternating pulses of environmental conditions, ie wet and dry phases. The communities of pulse stable systems are characteristically very resilient to change, but it has been suggested that, as a result of this, they are fragile in the face of stable conditions (Denny 1985).

The ability of communities to survive dramatic environmental events such as drought, disease and fire results from the plant's adaptive responses to a defined disturbance regime. These mechanisms also enable survival following other events. In some vegetation types, it appears that some fire dependence has evolved along with fire adaptations and evidence suggests the ecological effects of fire are as diverse and complex as the fire regimes and the communities they affect.

6.2.1 Fire and its effects on wetland vegetation

Wetlands contain a wide variety of plants including submerged and floating aquatics, emergent reeds and rushes, perennial and annual grasses, sedges, small to large shrubs and trees. The spectrum of plant life forms present in any wetland and the consequent fire regime will vary markedly with local environmental conditions. The most important determinant of the effects of fire on the long-term structure and composition of vegetation communities is fire frequency, followed by season of burn, and lastly intensity (Tolhurst 1985). Gore (1983) suggests that the severity or intensity of a fire event is a significant factor in wetland ecosystems. Burning seldom affects a wetland area uniformly. The presence or absence of free (standing) water and the spatial and seasonal variations in the wetness of the surface organic layer will influence a fire's severity, rate and extent of spread. The recovery from fire will also depend on the fire frequency, vegetation composition, community age and condition and the post-fire weather conditions.

The responses of wetland plants to fire are not well documented. Some generalisations can be made, however, based on existing studies and the known biology and responses of those plant types associated with wetlands. Wetland environments are dynamic, changing with periodic drying and wetting, and wetland plants have adaptations to allow them to cope with regular change. Many wetland plants are monocotyledons and rhizomatous, and the buds and growing points of plants in these groups are often protected from fire by the leaf bases or by being insulated below ground level. Germination of seeds following disturbance and exposure of the substrate (Smith and Kadlec 1983, Pederson and van der Valk 1984) is also common. These adaptations and characteristics provide much of the vegetation found in wetlands with the ability to survive a fire event without any long-term ill effect. Fires that damage the vegetation before it has regenerated from the last fire may kill some plants, retard reproduction and eliminate seed stores.

Species responses

When examining the overall response of a species to fire it is necessary to examine not only the effects of a single fire on the various life stages, but also to ascertain the effects of repeated fires and fires at different levels. When individuals or even whole populations are killed by a single fire event, the species may persist as soil-stored seed within the burnt area, or receive seed from outside the burnt area. Noble and Slatyer (1981) recognised two broad response types; the Obligate Root Regenerator/Resprouter where plants recover, and the Obligate Seed Regenerator, where mature plants are killed by fire but a new plant regenerates from seed. While this classification is readily applied to woody species, it may be difficult to apply to the herbaceous species and monocotyledons, both of which are well represented in wetlands. Gill (1981) suggests that further research is required into the responses of herbaceous species to fire.

In communities subject to fire, plants have developed strategies to cope. One is the ability to reproduce vegetatively. Such a strategy means that a plant need only be one or two years old to have reproductive capacity. In wetlands, the predominant form of regeneration is from lignotubers, tubers and rhizomes (Specht 1981). Where fires are of low intensity or where the vegetation is growing in soil saturated with water, the underground organs are protected from heating (Good 1978, Gellie 1980, Gore 1983).

The regenerative capacity following fire of both *Typha* spp. and *Phragmites australis* are well documented (Van Der Toorn and Mook 1982; Thompson and Shay 1985, 1989; Mallick and Wein 1986). Observations of *Typha* sp. burnt on the Gunbower Creek in northern Victoria demonstrate the insulating properties of the saturated substrate and the regenerative capacity of rhizomes under good growing conditions. A high intensity fire in early January 1990 burnt the *Typha* bed growing over water. By the last day of March that year the burnt plants had returned almost to their pre-burn height.

The effects of fire on lignum *(Muehlenbeckia cunninghamii)* have also received some attention, where fire has been used as a means of control to aid grazing. A study by Pressland and Keenan (1985) concluded that 'fire is more effective than chemicals in quickly and deleteriously affecting lignum'. The study found that while lignum can recover from 'cool' fires, plants may be killed outright by 'hot' fires, (basal suckering followed fire in 52-76% of the plants burnt during the course of the study). Lignum suckers and seedlings are palatable to grazers, will be selectively grazed by stock, and as a result, regeneration may be severely impaired or plants killed where heavy grazing follows fire.

For those species where regeneration from seed is the main or a significant mechanism for recovery after fire, the timing of fires in relation to reproductive maturity, or for annuals, the timing of seed shed, is most important.

Where species regenerate from seed, germinating seedlings can be excluded early in their development where rootstock regeneration is vigorous. In many species, seedling survival is best on grossly disturbed sites where competition with established plants is minimal, or where changed environmental conditions allow colonisation to take place (Beare and Zedler 1987).

Shrubs and trees associated with wetlands (eg members of the genera *Leptospermum, Melaleuca, Callistemon* and *Eucalyptus)* rely on a combination of seedling, rootstock and bud resprouts for regeneration. Resprouting from epicormic buds and lignotubers following low intensity fires enables strong recovery under favourable climatic conditions. Seedling germination in these circumstances replaces chance losses of the existing plants from excessive heat damage, poor plant condition or unfavourable post-fire weather conditions. High intensity fires in summer resulting in a high proportion of plant death due to heat damage may result in a greater proportion of regeneration from seed.

Underground organs and seed stores may be destroyed where fires burn the surface organic layer or, under severe conditions, burn the sub-surface peat. Slow recovery and absence of some smaller plant species have been noted on sites burnt under conditions of dry peat and moderate to severe fire weather (Gellie 1980).

Frequent fires (ie less than five years) can lead to a reduced seed store or a complete lack of seed for those species that require a minimum fire-free period in which to set seed. Frequent fires can also lead to a depletion of the food and bud reserves of resprouters. A single fire event is unlikely to eliminate any species in the long term. However, frequent and high-intensity fires may result in the loss of species from a site. This will depend on the type of wetlands, soil moisture and water level.

Community responses

Studies of the Aboriginal occupation of south-western Victoria indicate that the burning of wetland vegetation has long been associated with the exploitation of wetland resources by Aboriginal people. Charcoal and pollen evidence suggest that over the last 6800 years 'continuous low-intensity firing [of wetland vegetation] has occurred without altering the regional vegetation', and 'swamp plants have probably been harvested (and fired) for the last 6800 years, with no.. .apparent diminution of the resource base in that time' (Head 1983, 1988). Such studies suggest that some wetland vegetation communities can tolerate frequent fires without suffering gross changes in species composition. Meredith (1988) recommends that such evidence be considered cautiously, as the resulting data from pollen and charcoal sampling are fraught with 'major and unassessed biases caused by the mode of deposition. ..and the methods of analysis', and that such data allow only the broadest inferences to be drawn.

An obvious consequence of fire in any vegetation type is the immediate change in the plant cover on the site. A change of cover alone, independent of the other direct and indirect effects of fire, will have an effect on distribution, abundance and diversity of species in that community over time. Gellie (1980) found in a study of fire ecology of Button Grass *(Gymnoschoenis sphaerocephalus)* moorlands, that the open conditions following a mild intensity fire stimulated germination and flowering in a number of wet-heath species. Burning *Typha* and *Phragmites*-dominated marshes in Canada has been observed to lead to a short-term increase in species diversity and richness (Mallick and Wein 1986, Thompson and Shay 1989). Vogl (1973) reported, from studies of a Florida wetland, that burning wetland litter may reduce levels of toxic allelochemicals responsible for inhibiting plant growth and regeneration.

The species composition of fire tolerant communities is unlikely to change following a single fire event that is compatible with the prevailing fire regime. Meredith (1988) and Noble and Slatyer (1981) advance the initial floristic composition model—that is, what was there prior to fire will return after fire—as the one most likely to apply to Australian ecosystems. All the species present at a particular site will usually not be present as mature plants at the one time, but will be present as either adults or propagules, eg seeds or bulbs. Where fire is a more frequent event than can be tolerated by the species present, changes in community composition will occur as intolerant adults are eliminated and soil-stored seed exhausted. In the absence of fire, long lived species and those that can regenerate in the presence of their own adults will finally become dominant.

Some authors have suggested that fire has a role in maintaining some wetland vegetation communities at a sub-climax stage. In a report on plant succession following fires in the Okefenokee swamps, south-eastern USA, Cypert (1972) concludes that in the absence of fire 'it is obvious that they (the prairie swamps) are now ... reverting to swamp forest'. Similarly, Denny (1985) reports that the forest/grassland mosaic wetlands of Zaire 'appear to be fire maintained: they are certainly very regularly burned today', but qualifies this by stating 'Whether they would be seral to forest if fire could be excluded is uncertain'. Paijman *et al.* (1985), states that the imposed fire regimes that followed European settlement in Australia kept 'many areas of heath swamp in a more or less permanent state of disclimax'. While the vegetation 'climax' model is probably not relevant to the South-east Australian situation, there is some evidence to suggest that fire has a role in maintaining some Victorian wetland vegetation types, such as wet heath and wet grasslands, in particular seral stages (D. Frood pers. comm.).

Fire is likely to result in short-term increases in nutrient availability (see Section 6.2.3), and this combined with little competition for space (light) may allow colonisation by weed species (Vogl 1967, Gore 1983). The invasion of natural communities by introduced species is always preceded by disturbance (Fox and Fox 1986). There is a trend to greater invasion with more prolonged or intense disturbance. The threats posed by weed invasion to the integrity of isolated or remnant vegetation communities are now well documented (Groves and Burdon 1986).

Fire is likely to influence structure and this has important implications for wildlife.

6.2.2 The effects of fire on wetland fauna

Much of the Australian research effort into the ecological effects of fire has been directed to dry forest and heathland communities. This is certainly the case for the native fauna, and even within the forest fauna taxa, few species have been studied. Little is known about the effects of fire on the faunal groups which inhabit or have a strong association with wetland habitats. Those species that have been subject to some investigation include the Ground Parrot *(Pezoporus wallicus),* Swamp Rat *(Rattus lutreolus),* and *Antechinus* species.

The impacts of different fire regimes on wildlife are difficult to assess unless the responses of the vegetation can be predicted and the site dependence of the species is known. A few basic assumptions can be made:

The effects will depend on the area and intensity of the burn, as survival is largely a function of intensity. Most vertebrate groups can escape low intensity fires by avoiding the fire edge or sheltering until the fire front has passed. The most dramatic effects are likely to result from low frequency, high intensity, broadscale summer fires, such as the Ash Wednesday fires of 1983. Tolhurst (1985) reports that studies of the effects of fires of this type show the following survival of various faunal groups, most of which are associated with or have links to wetlands:

• Rabbits, potoroos	High survival
• Goannas, possums, bandicoots	Poor survival
• Small marsupials, rodents	Very poor survival
• House Mice	Extremely high survival
• Wallabies, kangaroos	Poor survival
• Other reptiles, amphibians	Good survival
• Birds	
-bark gleaners	High survival
-honeyeaters	Poor survival
-canopy feeders	Poor survival

Such observations are also consistent with the idea that the survival of fauna depends on the effect fire has on the animal's habitat. Where burns are patchy, small fragmented colonies may survive to recolonise burnt areas as suitable habitat develops. The intensity of the fire will also have a bearing on the development of post-fire habitats. Low intensity fires will frequently produce a patchy burn and thus a greater diversity in the resulting vegetation patterns. Suckling and Macfarlane (1983) report that low intensity forest fires generally leave 25% of an area unburnt.

ii The effects will depend on the post-fire recovery of the vegetation. While a single fire event will not alter the plant species composition of a site, it will lead to changes in the vegetation structure and the phenology of individual plant species, and thus alter the availability of cover and food resources. Fire undoubtedly aids the development of hollow limbs in eucalypts (Suckling and Macfarlane 1983), although intense fires would be expected to cause substantial losses of hollow-bearing trees.

iii Some species may show a preference for a particular stage in the post-fire development of vegetation. Catling and Newsome (1981) and Meredith (1988) conclude, however, that there are few fire specialist species in the indigenous vertebrate fauna. The rate of post-fire population recovery will depend on the development of suitable habitat. This will be in part a function of diet and be slowest for species of higher trophic levels.

iv While individuals from a population may be lost, the natural fire regime of the site should not result in the loss of species from the site.

v Post-fire mortality will be high for species with limited mobility, where the loss of cover enhances predation and food resources are limited or absent.

Invertebrates

It can generally be assumed that fires which substantially alter habitats by consuming standing vegetation and litter would have a substantial impact on the species and populations of surface dwelling invertebrates. In forests, fire regimes and/or intensities which enable the build-up of litter and other shelter sites soon after fires are likely to provide conditions conducive for recolonisation and repopulation by invertebrates. Meredith (1988) reports that the litter fauna tends to recover more slowly after fire than does the soil fauna.

In a report on the biology and conservation of the Damselfly (*Hemiphlebia mirabilis),* Sant and New (1988) state that habitat change is regarded as the most damaging factor to ecologically-sensitive insect species. The report cited fire in heathland adjoining wetlands as a contributing factor in the decline of *Hemiphlebia* at Wilsons Promontory, Victoria. Sant and New (1988) also reported that while the direct effects of fire on *Hemiphlebia* are unknown, many other aquatic invertebrates persisted in the study area 'despite substantial amounts of ash in the water and reduced vegetational [sic] cover'. Fire-induced changes in water quality, ie turbidity, temperature and chemistry, are likely to have an effect on wetland productivity, and changes in the invertebrate populations are likely to be useful indicators.

Reptiles and amphibians

There are few data on the effects of fire on the Australian reptile and frog fauna. As for other groups, mortality will depend on fire intensity, and post-fire mortality may be high where the loss of cover enhances predation and food resources are limited or absent. It can be assumed that mortality from fire will be reduced where adequate shelter sites exist, and in wetlands, the presence of free-water would provide refuge for some members of this group

Mammals

Some studies on the effects of fire on small mammals have included species which inhabit wetlands. In a Tasmanian study, Gellie (1980) found that small colonies of Swamp Rats *(Rattus lutreolus velutinus)* survived fire in unburnt pockets of Button Grass and associated sedgeland vegetation. Other observations from the same study showed that Swamp Rats returned to a burnt site six years after a fire of mild intensity.

Catling and Newsome (1981) cite a study of the post-fire recovery of small mammal populations in Nadgee Nature Reserve, where researchers found that:

- the biomass of Swamp Rats and Bush Rats *(Rattus fuscipes)* in dune swale and swamp habitats peaked five years after fire;
- Brown Antechinus *(Antechinus stuartii)* and Dusky Antechinus *(A. swainsonii)* recovered to pre-fire levels at nine years after fire; and
- House Mice *(Mus musculus)* experienced a short-lived boom at three years post-fire, followed by an equally sharp decline to pre-fire levels at four to five years.

This study concluded that the recovery of rodents was most rapid and marked in the dune swale-swamp habitats.

Birds

The use of habitat by birds is strongly correlated with structural diversity. Habitat value may be increased for some species where a patchy fire has resulted in a range of vegetation age classes. Weller (1978) and Smart (1974) report that waterfowl productivity is enhanced by heterogeneity in wetland vegetation, and it is the structure rather than the taxonomic composition of emergent marsh plants that is of greatest importance to nesting birds, 'most species favour a hemi-marsh, where a 1:1 water—vegetative cover interspersion exists'.

Vogl (1973) found that shoreline use by birds increased by 300% following an experimental winter burn of a northern Florida wetland. The author suggested that the increased use of the shoreline was a result of the removal of accumulated plant material and an increased palatability of the vegetation as a rapid growth response following burning.

The response of all bird species to fire is to move away from the fire front. Gellie (1980) reports that Ground Parrots 'are not easily disturbed and will fly when the fire front is close by'. The success of attempts to flee fire will depend on the mobility of the species involved and the intensity of the fire, and it is generally reported that few birds perish in a low intensity fire. High intensity fires, however, will cause significant losses of individuals. Following fire, birds may suffer mortality due to starvation and predation. It is generally considered that while individuals are lost or displaced and thus numbers decline, few if any species are lost (Calling and Newsome 1981).

Fires occurring when birds are nesting and before young have fledged are likely to have serious effects on bird populations. Fire is likely to pose a considerable threat to colonial nesting sites in wetlands, and long-term disruption of breeding could result where colonies show a strong site dependence.

6.2.3 Fire and effects on nutrient cycling in wetlands

Soil fertility is a fundamental factor controlling the functioning of plant communities. Many Australian ecosystems are characterised by soils which have a low reserve of nutrients, particularly nitrogen (N) and phosphorus (P) and support plant species that are adapted to low soil fertilities.

Fire influences the physiochemical properties of soil by oxidising the standing vegetation cover and, depending upon the soil moisture conditions (particularly relevant to wetlands), oxidises soil organic matter. Fire directly affects the soil and litter environment by inputs of heat and ash and by modifying the microclimate. In the short term, fire mobilises nutrients by incinerating organic material, leading to the deposition of ash and by heating the soil. Not all elements are mobilised equally, however. Offsetting these nutrient inputs and improved availability to plants, is the nutrient loss by leaching, run-off, the erosive action of the wind and losses to the atmosphere in smoke. Raison (1980) reports that the effects of fire on nutrient cycles are dependent on specific ecosystem processes. These are determined by the interaction between the soil, climate and vegetation. Where the rates of litter decay and mineralisation are slow, a relatively sudden redistribution and short-term mobilisation of nutrients may follow burning.

Work undertaken to date on the effects of fire on Australian soils gives only a guide to the nature and magnitude of the effects on dryland systems, nutrient pools and nutrient cycling processes, and such studies deal largely with nutrient cycling in eucalypt forests. A study of nutrient loss from eucalypt litter during a fire of low intensity indicated that 60% of the N and 50% of the P content of the litter is lost from the site in smoke (Raison 1980). Results of studies throughout the world indicate that there can be a significant loss of N, but in Australia the availability of P is increased and this is probably most significant for communities on nutrient-poor sites.

Where fire occurs in combination with grazing, prolonged drought, vehicle traffic and removal of nutrients in timber, nutrient losses from a site are likely to be exacerbated (Walker et *al.* 1986).

In a study of nutrient mobilisation in a *Spartina* and *Juncus*-dominated marsh community in Utah, Faulkner and de la Cruz (1982) estimated losses of 70% for N and 40% for potassium (K) from combustible plant matter. Such losses include both losses in smoke and losses as ash. The retention of ash on a site may largely be a function of climate. It was reported during the above study that 30% of the particulate-borne (ash) nutrient was deposited down-wind of the burn site. The nutritive responses of the *Spartina—Juncus* community to burning were investigated in the same study. The researchers observed increases in the absolute elemental concentrations, particularly in regard to N, in the spring regrowth that followed burning. Enhancement of the sediment nutrient pool was also noted, but was limited to the top two centimetres. Surface pH was also slightly elevated in the short term. It was not clear from this study that the increases in the nutritive status of the regrowth could be attributed directly to nutrient mobilisation, or whether other factors such as insolation, resulting in early sediment warming, and mulch removal may have stimulated plants to take up nutrients from the site.

Smith and Kadlec (1984) tested the hypothesis that burning improved the nutritive quality of marsh plants, and found that crude protein increased in the regrowth that followed burning in three of the four species under study: *Distichlis* sp., *Scirpus* sp. and *Typha* sp. The ability of non-ruminant wetland vertebrates to digest the resultant vegetation, a function of the cellulose, hemicellulose and lignin content, was little changed, however. Northern hemisphere studies of grazing geese reveal that there is some selectivity for grasses high in protein, and that concentrated feeding activity resulted in regrowth with a higher protein content. Other studies indicate that some species select the most nutritious plant parts in relation to their needs. It is not known if wetland fauna respond to the higher protein levels of burned vegetation with increased grazing and thus improve reproductive performance.

6.2.4 Fire and wetland hydrology

The effects of fire on catchment hydrology depend on the intensity and the season of the burn, the post-fire climate, the rate of vegetation recovery, the time between fires, the nature of the soil, the topography and how soon rain falls after fire. The general effects can include decreased interception of rainfall due to loss of vegetation and litter cover, increased stream flows, increases in suspended sediment loads, soil erosion and reduced infiltration (Meredith 1988, Raison 1980). Data on changes in water chemistry, the effects on the aquatic biota and qualitative changes in catchment hydrology are lacking. Readers are referred to Gill *et al.* (1981) which expands on the above, and Gill and Noble (1989) for a comprehensive bibliography on fire and its effects on hydrology.

6.3 THE PROTECTION OF WETLANDS FROM UNPLANNED FIRE

6.3.1 Background

The perceived threats that arise from fire are frequently the threats to human values and not biological values. NRE policy is historically based on the protection of assets rather than biological values. Fire protection must aim to manage the risk and protect both the human and biological values of the area being managed. Some wetlands may require additional protection.

An increase in the likelihood of fire is often associated with human use patterns and activities, and people are significant contributors to the fire risk of a particular area (Tables 6a and 6b). The environmental benefits provided by protecting sensitive biological values from fire must also outweigh the environmental costs of undertaking any fire protection works. These environmental costs may include loss of vegetation, destabilisation of soil and the establishment of pest plants and animals.

Measures that can be undertaken to safeguard wetlands against the detrimental effects of fire include:

- providing vehicular access to the wetland;
- undertaking boundary protection and providing access;
- undertaking overall protection and providing access;
- providing access to a water supply; and
- controlling the use of fire for cooking and warmth.

6.3.2 Fire prevention: reducing the incidence of fire

Fire prevention includes all activities concerned with minimising the incidence of unplanned fire. It includes education, extension and enforcement. Planning for fire protection must outline strategies to prevent or reduce the incidence of fire.

Statistics on the incidence of fire by cause and agency are not available for wetland fires. The available statistics for all fires attended by NRE for the period 1986-89 that relate to wetlands (ie a likely cause or agent in wetlands) are set out in Tables 6a and 6b. These statistics indicate that there exists a carelessness, ignorance or deliberate disregard for fire regulations by the agents listed, all of whom could be considered to be potential users of wetlands.

Table 6a Fires by cause (as a % of all fires) (Source: *CFL Annual Reports* 1986-89)

Forest utilisation	Campfire escapes	Cigarette or match	Deliberate	Lightning	Unknown
9.9	9.0	11.1	16.4	23.3	7.0

Table 6b Fires by agency (as a % of all fires) (Source: *CFL Annual Reports* 1986-89)

Children	Camper	Shooter Angler	Day visitor	Grazing lessee	Forest industry	Forest agency	Unknown
5.0	5.3	3.5	3.6	0.4	1.6	1.2	2.1

Education and extension

Education and extension activities have long been recognised as useful land management tools. Such activities seek to inform and change the attitudes of target groups so that they are sympathetic to the aims of land managers and comply with the regulations promulgated to protect land values. User groups identified as at risk from fire on public land or whose activities are a potential source of ignition are worthy of particular attention and education campaigns. Target groups for wetlands will include hunters, anglers, campers, four-wheel drivers and commercial users such as licensed graziers, commercial anglers and forest workers.

6.3.3 Fire pre-suppression: reducing the impacts of fire

Pre-suppression activities aim to reduce the impacts and spread of unplanned fire. These activities include construction and maintenance of firebreaks, maintenance of access, provision of suitable water supplies and provision of a suitably equipped and trained fire-fighting force. The identification of fire sensitive areas and features is also an important part of pre-suppression planning.

The need for pre-suppression activities will be determined by the fire history, weather patterns, topography, vegetation patterns, the assets to be protected and the aims of management. The pre-suppression needs will vary for each area being managed.

Access

A vehicular track network serves two basic functions. It allows managers to carry out maintenance and management works, and allows the public vehicular access. These two objectives may be complementary, but visitor vehicular access can be restricted to manage visitor use and the consequent fire risk. Vehicle tracks can also serve as firebreaks. A review of access and the track network is one of the first tasks to be undertaken during pre-suppression planning.

Providing strategic access of a suitable standard to facilitate a level of fire suppression appropriate to the wetland is the minimum pre-suppression work that managers should expect to undertake. A suitable standard of vehicular access is essential for quick and effective fire suppression. Moreover, it is required to safeguard the lives of staff involved in suppression activities and to enable the evacuation of the public threatened by fire.

Victorian wetland wildlife reserves have historically suffered from a proliferation of vehicle tracks. Some are well defined and used throughout the year. Many others are, however, poorly defined and may only be used during high-use periods, such as during duck season or summer holiday periods. In the face of a fire emergency, ill-defined and dead-end tracks pose a serious threat to both fire fighters and visitors. Uncontrolled access can compromise and damage nature conservation values, lead to the establishment of pest plant and animal populations, and enhance the fire risk.

Firebreaks

Firebreaks have long been used as a fire protection technique to interrupt fuel beds and to provide control lines and access. Fire breaks take a number of forms. All involve removing reducing vegetation and litter. A well maintained firebreak should stop a low intensity fire (DCE 1990). For higher intensities, the prime purpose of firebreaks is to provide safe and effective control lines for fire fighting focus, and to provide a base for backburning.

Firebreaks of any width are regarded as ineffective against severe fire unless strengthened by significant adjacent fire treatment (DCE 1990). Wilson (1988) and Macarthur (1966) state that fires of an intensity too high to be contained by tanker units can still have a low probability (1%) of breaching a 10-metre-wide firebreak. Firebreaks parallel to severe fire can be useful for flank attack, and the flank of a severe fire has been held by a firebreak of 10 metres (O'Bryan 1990a).

The width of the break will in part be determined by the constraints of the site and the nature of the vegetation. Firebreaks can be breached when winds are strong enough to transport burning debris. Eucalypt forest fires have a high spotting potential, and spotting several kilometres ahead of the fire front is common. The probability of a firebreak breach will also be higher in grasslands that contain large seedheads (such as those of Phalaris, *Phalaris tuberosa)* and other potential firebrands. Fire behaviour in low and open vegetation, such as may be encountered around some wetland types, is influenced by wind velocity and will be essentially wind driven. Fire behaviour will be a major factor in determining the effectiveness of a break in halting or retarding the spread of fire (Wilson 1988).

Firebreaks have the effect of simplifying habitat by virtue of removing or reducing the vegetation and litter cover. Firebreaks may hinder the dispersal of plants and animals. They also provide opportunities for erosion and the establishment of pest plant and animal populations. Apart from the environmental costs, the monetary costs of firebreak establishment and maintenance can be high. Before establishment proceeds, the benefits accrued from fire breaks in protecting the biological values and minimising the costs of and maximising the effectiveness of suppression activities must be demonstrated to outweigh the environmental costs. The positioning of firebreaks should also take account of aesthetic and landscape values.

A number of techniques to establish firebreaks are available to wetland managers; these include:

- mineral earth breaks. These are constructed using dozers, graders, scrapers, disking ploughs, and in some instances herbicides. Mineral earth breaks are the most destructive to vegetation, habitat and soil stability so are the least desirable type of firebreak. While there is a total removal of fuels from these breaks, their effectiveness depends ultimately on fire behaviour.
- slashed and trittered breaks. The height of fine fuels is a significant determinant of fire behaviour, such as rate of spread and suppression difficulty. MacArthur (1966) indicated that for grasslands on flat or gently undulating ground, a reduction in fuel height to 0.3 metres can reduce the degree of difficulty in suppressing fire to low to moderate for grassland fire-danger ratings of low and moderate. Burrows (1981) found that the reduction of fine fuels below tree vegetation can have a significant effect on fire behaviour. Slashing and trittering are accepted methods of reducing standing vegetative cover. Strategically placed slashed breaks allow for control and access under average (low—moderate) fire conditions.

Slashed and trittered firebreaks have a number of advantages over mineral earth and burnt breaks. Vegetative cover is more or less retained on the site. It reduces the degree of soil disturbance and exposure and thus erosion, and opportunities for colonisation by pest plants. Slashing and frittering can be carried out in almost any weather, but should be timed to maximise the fuel modification benefits prior to the fire season. Slashing can be precisely directed and controlled to achieve a particular result, eg cut height.

Fuel reduction burning

Fuel reduction burning is the planned use of fire to reduce fuel loads. It is an accepted fire pre-suppression method and is used extensively.

Meredith (1988) questions the value of fuel reduction burning practices in some instances, but states 'there is every reason to believe that strategic burning, especially to protect specific sites, is very effective'. The timing and frequency of fuel reduction burns relies on an understanding of the fuel dynamics of the site, and specifically the types of fuels and the rates of accumulation. Strategic low intensity burning to create corridors of low fuel may have some value for the protection of wetlands. The width of the break will be determined by the site and the local fire environment. Burning is likely to be a cheap fuel reduction method, particularly when it is carried out on a large scale. It is the only broad area treatment.

Frequent low intensity burning will adversely affect most vegetation communities. Frequent fires may eliminate some species and cause changes in the abundance and distribution of others. Low intensity burns are frequently patchy, however, leaving a mosaic of burnt and unburnt patches. Unburnt patches of vegetation provide important refuge and habitat for fauna, and provide structural diversity in the resulting vegetation.

Grazing

Grazing has long been promoted by graziers as a means of reducing standing fine fuels and the accumulation of well-aerated litter. There is, however, little evidence to support these claims. Stock are selective grazers, and in a free-ranging situation are unlikely to reduce total fuel loads to form an effective fuel-reduced break at a grazing level that does not compromise the nature conservation values of the site. Where areas can be strip grazed and stock are forced to consume or trample enough of the less palatable species, there may be some strategic fuel reduction benefits. In some instances, grazing will cause less flammable vegetation to be replaced by species which are more flammable, thus increasing the fire hazard (Department of Crown Lands and Survey 1977, Ashton and Williams 1989).

In a Western Australian study, Burrows (1981) evaluated the effectiveness of free-ranging cattle in reducing fire hazard. This study found that effective fuel reduction occurred only on sites where forage was of a high quality. On poor quality sites, there was no significant reduction in the fire hazard between pastures available for grazing and exclosures. The study concluded that the timing of grazing was significant in achieving a reduction in fuel levels, that the trampling of vegetation by stock contributes to the reduction of the fire hazard and that pasture must be heavily and uniformly grazed to offer an effective reduction in the fire hazard. High pressure grazing of conservation reserves for whatever reason is usually in conflict with their primary management objectives, and is not generally an acceptable fire management tool.

6.3.5 Fire suppression: putting out the fire

The suppression options available to the personnel responsible for putting out the fire will vary according to the availability of fire-fighting forces and equipment, the topography, access, water supply, vegetation type and the behaviour of the fire. Fire suppression techniques will ideally be in line with the management objectives of the area. Ultimately, it is the fire controller who decides what suppression techniques will be employed in any fire situation.

A number of widely and commonly used techniques are potentially damaging to wetlands where the primary aim of management is to conserve natural values.

- Grader and bulldozer trails. These can lead to gross soil disturbance resulting in erosion and a reduction of water quality, can aid the invasion of pest plants and animals and impede the recovery of vegetation along the trails (author's observation). Rehabilitating control lines can be expensive.
- Phosphorous and nitrogen-based fire retardants and nutrient-based wetting agents and foams. Such compounds may contribute to nutrient enrichment of the site, and lead to the establishment of both terrestrial and aquatic weeds or imbalances in the indigenous flora. Changes in the nutrient balance of wetlands is a major factor leading to the degradation of wetland communities, and any techniques which contribute nutrients to wetland systems should be avoided.
- The low impact techniques that minimise disturbance to the soil and vegetation. These include:

—the use of ground crews to clear fire breaks by hand;
—water applied from specially equipped four-wheel drive vehicles, tankers, tractors and boats;
—aerial water bombardments from helicopters and fixed-wing aircraft;
—back-burning; and
—non-nutrient-based biodegradable foam retardants.

The effort employed to suppress fire, and the environmental damage associated with particular suppression activities, should reflect the value of the assets and the importance and fire sensitivity of natural values to be protected.

6.4 MANAGING THE BIOLOGICAL VALUES OF WETLANDS WITH FIRE

6.4.1 Background

Despite the fact that fire is a natural element in the Australian environment, the use of prescribed fire in the management of biological reserves remains controversial. Some species have some dependency on fire for their continued existence. Thus fire will be required to maintain some communities (Good 1981).

Fire may have application in the management of wetland communities given that:

- it is one of the few major environmental factors over which some control can be exercised;
- it is recognised as a natural phenomenon affecting wetlands, and is one of the continuing physical factors of the Australian environment;
- some indigenous species of plants and animals are adapted to particular fire regimes, and it may be necessary to continue these regimes to ensure the long-term survival of species and communities;
- fire can have a role in the management of threatening processes, eg weed control; and
- prescribed fire is and will continue to be used as a fire protection technique.

Applying fire to achieve an objective related to the ecology of a particular community or species depends on knowledge of the post-fire recovery of the vegetation. The fire requirements of some communities are known (Meredith 1984, 1988), and while Gore (1983) may regard fire as second only to hydrology as an influence on wetland vegetation, very little is known of the effects of fire for most Victorian wetland communities.

6.4.2 A case study in the use of fire to manage wetland vegetation: regulating *Typha* spp. *and Phragmites australis* populations using fire

Phragmites australis and *Typha* spp. are rhizomatous perennial macrophytes whose aerial parts, the shoots, are annual. These plants typically form monospecific stands fringing bodies of shallow, fresh to brackish, still or flowing water. Bulky rhizomes and a tall dense canopy give these plants a competitive advantage over other species. Their extensive distribution suggests tolerance to a wide range of conditions.

It has been shown that wildlife use of large monospecific stands of these species can be less than in areas of varying structure or species composition (Schlichtemeirer 1967). The value of beds of these species as wildlife habitat should not be underestimated, however. *Phragmites australis, Typha domingensis* and T. *orientalis* are indigenous components of the flora of many wetlands, and any manipulation of populations of these species must be justified.

A number of studies have been undertaken in the northern hemisphere to determine the influence of environmental factors in regulating populations of species of *Typha* and *Phragmites.* The effects of fire and season of burn have received particular attention, viz van der Toorn and Mook (1982), Shay *et al.* (1987), Thompson and Shay (1985, 1989) and Mallik and Wein (1986). A number of variables which can affect the outcome of a burn include the time of burn, intensity of burn, the plant condition at the time of burning and the wetness of the substrate. Summer burning was found to have a deleterious effect on populations of these plants in temperate regions, inhibiting rapid growth.

Specifically, the effects include:

- reduced shoot biomass, ie shorter, thinner vegetative shoots;
- lower flowering shoot density (for *Phragmites);*
- reduced below ground standing crop and nonstructural carbohydrate content of rhizome (for *Phragmites).*

A Canadian study (Mallik and Wein 1986) has shown that the draining, summer burning and subsequent reflooding of a *Typha* sp. bed

- increased species diversity;
- reduced accumulation of organic material; and
- reduced *Typha* cover.

Burning to control these species in Victorian wetlands has not been documented.

It is not suggested that burning is the only or best method to control populations of these species. Burning may, however, be a cheap method if this is required in some situations, and have some advantages in removing accumulated litter and aiding rapid nutrient cycling.

6.4.3 Managing wetland wildlife habitat with fire

The structural and floristic diversity of wetland vegetation has been shown to be a significant influence on the extent and type of use made by wildlife in North American wetlands (Vogl 1967, Mihelson *et al.* 1974, Weller 1982), and fire has long been used to manage wetland vegetation for wetland wildlife in North America (Lynch 1941, Vogl 1961 and Smith and Kadlec 1984).

Very few Victorian wildlife species are currently managed using fire although many are markedly affected by fire regimes applied for other purposes (eg protection of plantations). Those that are include the Ground Parrot (Loyn 1989, Meredith 1984), Brolga *(Grus rubicundus)* (Arnol *et al.* 1984, Weber[6] *pers. comm.)* and Heath Rat *(Pseudomys shortridgei)* (Yorston[7] *pers. comm.,* National Parks Service Victoria 1985). Fire has also been trialed in the management of Hog Deer *(Axis porcinus)* habitat in the Gippsland Lakes (Kelly[8] pers. comm.). Other species where fire may have a role, include the New Holland Mouse *(Pseudomys novaehollandiae)* in the Grampians and at Langwarren, and the King Quail *(Coturnix chinensis)* on French Island. Loyn (1989) suggested that fire may have a role in the management of wetland vegetation to enhance duck habitat in Victoria.

The role of fire in managing wildlife habitat in Victoria was reviewed during a conference of the then Department of Conservation and Environment wildlife management (National Parks and Wildlife Division Victoria 1989). It recommended that despite the lack of understanding of the role of fire in the habitat requirements of species, the Department should formulate a set of interim guidelines for the management of wildlife using fire (Loyn 1989). Guidelines for the management of fuel reduction burning to minimise the impacts on forest wildlife have already been attempted in the Departmental document, 'Forest Management Guidelines For Wildlife Conservation' (Victorian Government 1988).

6.5 MONITORING FIRE IN WETLANDS

There is a lack of detailed information on the nature and extent of the fires that occur each year in wetland environments. A systematic and conscientious approach to recording even the basic details of these fires is needed so that the true nature of the threat and the effects of fire on wetlands can be determined.

The aim of monitoring is to identify changes over time: it is based on the ongoing observation and recording of events on-site. Fire is a significant environmental factor with the potential to induce great change. If its role in managing wetland communities is to be understood, its effects must be monitored. Where fire is applied to achieve a particular management objective, monitoring will determine if those objectives are being met.

Successful monitoring should have a clear objective, be systematic and be readily replicated. Moreover, monitoring to collect information essential for management should be seen as a management priority. It is recognised that monitoring can be a costly undertaking, but the knowledge that results from well designed and implemented projects may provide information that leads to a long-term cost saving. The benefits that result from such an information gathering exercise should not be under estimated. The details of any monitoring program will depend on the objectives and information needs.

---

[6] R. Weber, NRE Shepparton, Victoria.

[7] B Yorston, National Parks Service, NRE, Victoria.

[8] P Kelly, NRE Bairnsdale, Victoria.

6.6 SUMMARY OF MAJOR RECOMMENDATIONS FOR MANAGING FIRE IN WETLANDS

- **Fire Protection Officers should consult with wetlands planning and management staff to ensure that the fire protection issues and works relevant to wetlands are considered during the formulation or updating of fire protection plans and works programs.**
- **Where wetland management plans are produced, these should identify the fire protection measures needed to protect the wetland.**
- **Where existing regulations are inadequate, regulations controlling the public use of fire should be reviewed to ensure that the fire risk to wetlands is minimised.**
- **The conditions applying to commercial licences and permits issued for areas that include wetlands should, at the discretion of the Manager, allow for the prohibition of the use of fire in wetland areas.**
- **Access to and within all wetland reserves should be reviewed as a high priority.**
- **Where necessary, a strategic track network should be established and or maintained to provide access for fire protection** vehicles
- **Wherever possible, sections of the access track network will serve as part of the firebreak network.**
- **Fire breaks should be established only where there is a demonstrated fire hazard.**
- **Firebreaks should not be constructed in the marginal vegetation where the substrate remains wet over summer, or intrude on low herbaceous (non-flammable) vegetation types.**
- **Firebreaks should, where practical, be confined to the dryland vegetation buffer of wetland areas, and be constructed as far away from trees as possible.**
- **Those techniques that minimise soil disturbance and the removal of vegetation are preferred, and these should be used over other high impact techniques.**
- **Internal firebreaks should aim to maximise the strategic benefits provided by the existing track network or natural features, eg tracks or features on north-south/east-west alignments.**
- **Fuel reduction burning should only be used as a method of establishing firebreaks.**
- **Where prescribed experimental burns are to be conducted for ecological reasons, locations should be reviewed to maximise any fire protection benefits.**
- **All burning should be carried out in accordance with existing fire management guidelines and regulations.**
- **The free-range grazing of domestic stock should not be used as a fuel reduction technique in or around wetlands.**
- **The fire controller in charge of any suppression activity should endeavour to protect fire-sensitive natural features, both from fire and from potentially damaging fire suppression activities.**

- Wetlands will not be modified in any way to enhance the quality, quantity or duration of their water storage capacity for fire suppression purposes.
- Where water in a wetland is required for fire suppression purposes, it should be obtained in an environmentally sensitive manner.
- Suppression techniques that result in the gross disturbance of soil and vegetation (eg construction of mineral earth firebreaks by grader or bulldozer), or which lead to nutrient enrichment (eg use of nutrient-based retardants or surfactants), should be avoided.
- Fire responses of wetland species need to be documented.
- Wetlands need to be classified as to community responses to fires of different frequencies.
- Where wetlands occur in fire management zones leading to unacceptable fire frequency, special protection may be required.
- Any ecological application of fire in wetlands should have a clear management goal, conform with the principal management objectives of the wetland or wetland dependent species, and have a high chance of achieving the specified goal, based on the available information. Such activities should not adversely affect any fire sensitive communities or rare or significant wildlife.
- All fires, fire protection and suppression works and the results of post-burn monitoring should be fully documented.
- Fire should not be used to manage alpine wetlands or vegetation communities on dry peats.
- In general communities rather than species should be managed.
- The management of wetlands should generally aim to maintain habitat heterogeneity.

6.7 REFERENCES

Arnol, J.D., White, D.M. and Hastings, I. 1984. Management of the Brolga *(Grus rubicundus)* **in Victoria.** Resources and Planning Branch Technical Report Series No. *5.* **DCFL, Melbourne.**

Ashton, D.H and Williams, R.J 1989. Dynamics of the sub-alpine vegetation in the Victorian region. In : R. Good (ed.). The Scientific Significance of the Australian Alps. Australian Alps National Parks Liaison Committee, Canberra.

Australian Forestry Council 1987. Australian Bushfire Research. Report by the **Standing Committee on Forestry, ACT.**

Beare, P.A. and Zedler, J.B. 1987. Cattail invasion. Estuaries 10.

Bradstock, R. 1986. Plant population dynamics under varying fire regimes; PhD Thesis summary. Australian Journal of Ecology **11: 425-426.**

Burrows, N.D. 1981. Fire Hazard reduction by grazing cattle in *Pinus radiata* **D Don Plantations in the Blackwood valley.** Forest 'Department of Western Australia, Research paper No. 67.

Burrows, N., McCaw, L. and Friend, G. **1989. Fire management on nature conservation lands.** Occasional paper 1/89. Department of Conservation and **Land Management, Perth.**

Cartwright, B.W. 1942. Regulated burning as a marsh management technique. Transcripts of the North American wildlife and natural resources conference No. 7: **257-263.**

Catling, P.C. and Newsome, A.E. 1981. Responses of the Australian vertebrate fauna to fire: an evolutionary approach. In : A.M. Gill et al. **(eds).** Fire and the Australian Biota.

Chesterfield, E.A. 1985. Changes in the vegetation of the river red gum forest at Barmah Victoria. Australian Forestry **49 (1): 4-15.**

Clinnick, P. F. 1987. Monitoring the effects of fire—Soil and water. In: DCE (ed.). Monitoring the Ecological Effects of Fire. Department of Conservation and **Environment, Melbourne.**

Cypert, E. (1972), 'Plant succession on burned areas in Okefenokee swamp following the fires of 1954 and 1955', in Proceedings of the annual tall timbers fire ecology *conference* no 12 , Florida.

de la Cruz, A. A. and Hackney, C. T. 1980. The Effects of Fire on the Vegetation Structure and Primary Productivity of a Tidal Marsh. Mississippi Alabama Sea **Grant Consortium, Ocean Springs Mississippi.**

Denny, P. 1985. The Ecology and Management of African Wetland Vegetation, Dr **W Junk, The Hague.**

CFL, 1987. Monitoring the Ecological Effects of Fire. Fire Research Liaison Working **Group. Department of Conservation Forests and Lands, Melbourne.**

CFL, 1987. Report of the Department of Conservation Forests and Lands for the year ended 30 June 1987, Government Printer, Melbourne.

CFL, 1988a. Forest Management Guidelines for Wildlife Conservation. Lands and **Forests Division, Department of Conservation Forests and Lands, Melbourne.**

CFL, 1988b. Report of the Department of Conservation Forests and Lands for the year ended 30 June 1988. Government Printer, Melbourne.

CFL, 1988c. Guidelines for the Preparation of Regional Fire Protection Plans. Fire Protection Branch, Department of Conservation Forests and Lands, Melbourne.

CFL, 1989. Report of the Department of Conservation Forests and Lands for the Year Ended 30 June 1989. Government Printer, Melbourne.

CFL, Water Victoria and Ministry for Planning and Environment 1988. Wetlands Conservation Program for Victoria. Government of Victoria, Melbourne.

DCE 1990a. Fire Protection in Softwood Plantations —Draft Discussion Paper. Fire Protection Branch, Department of Conservation and Environment, Melbourne.

DCE 1990b. Draft Fire Protection Guidelines for Softwood Plantations. Fire Protection Branch, Department of Conservation and Environment, Melbourne.

CFL 1990. Proposed Barmah Management Plan Barmah State Park Barmah State Forest. Benalla Region, Department of Conservation Forests and Lands, Melbourne.

Department of Crown Lands and Survey 1977. Grazing on Crown Land. Government Printer, Victoria.

Dexter, B.D. 1978. Silvicultural management of Red Gum forests of the central Murray. In : Proceedings of the Royal Society of Victoria 90 (1) : 175-191.

Ealey, E.H.M. (ed.) 1983. Fighting Fire With Fire—a Symposium on Fuel Reduction Burning. Monash University, Clayton.

Faulkner, S.P. and de la Cruz, A.A. 1982. Nutrient mobilisation following winter fires in an irregularly flooded marsh. Environmental Quality 11 (1).

Finlayson, C.M., Roberts, J., Chick, A.J., and Sale P.J.M. 1983. The biology of Australian weeds: ii. Typha domingensis Pers. and Typha orientalis Presl. The Journal of Australian Institute of Agricultural Science.

Fox, A. 1978. The 1972 fire of Nadgee Nature Reserve, as cited in Catling, P.C. and Newsome, A.E. 1981

Fox, M.D. and Fox, B.J. 1986. The susceptibility of natural communities to invasion. In : P.H. Groves, and J.J. Burdan (eds). Ecology of Biological Invasions. Australian Academy of Science, Canberra.

Fox, M.D. and Fox, B.J. 1986 The effects of fire frequency on the structure and composition of a woodland understorey. Australian Journal of Ecology 11: 77-85.

Gellie, N.J.H. 1980. Fire ecology of Buttongrass moorlands. Forestry Commission of Tasmania Bulletin No. 6. Hobart.

Gill, A.M. 1977. Management of fire-prone vegetation for plant species conservation in Australia. Search 8 (1-2).

Groves, R.L. and Burden, J.J. 1986. Ecology of Biological Invasions : an Australian Perspective. Australian Academy of Science, Canberra.

Gill, A. M. 1981. Coping with fire. In : A. J. McComb (ed.). The biology of Australian plants. University of WA Press, Perth.

Gill, A. M., Groves, R. H. and Noble, I. R. 1981. Fire and the Australian biota. Australian Academy of Science, Canberra.

Gill, A.M. and Noble, I. R. 1989. Bibliography of Fire Ecology. Bush Fire Council of NSW, Sydney.

Good, E.R. 1978. Freshwater Wetlands: Ecological Processes and Management Potential. Academic Press.

Good, R.B. 1981. **The role of fire in conservation reserves. In : A. M. Gill** et *al.*. (eds). Fire and the Australian biota.

Good, R.B. 1978. **Adaptations of Australian plants to fire. In :** R.H. **Luke. and A.G.** Macarthur (eds). *Bushfires* in Australia. **Australian Government Printer, Canberra.**

Gopal, **B., Turner,** R.E., **Wetzel,** R.G. **and** Whigham D.F. (eds) 1982. Wetlands Ecology and Management. **National Institute of Ecology and International Scientific Publications, Jaipur.**

Gore (ed.) 1983. Ecosystems of the World, *4B* Mires: Swamps, Bogs, Fen and Moor. **Elsevier Scientific Publishing Company.**

Groves, R.L. **and Burden,** J.J. 1986. Ecology of Biological Invasions: an Australian Perspective. **Australian Academy of Science, Canberra.**

Gullan, P.K. 1978. **Vegetation of the Royal Botanic Gardens Annex at** Cranbourne, **Victoria.** Proceedings of the Royal *Society* of Victoria 70:225-240.

Head, L. 1983. **Environment as an artefact: a geographic perspective on the Holocene occupation of southwestern Victoria.** Archaeological Oceania **18:73-80.**

Head, L. 1988. **Holocene vegetation, fire and environmental history of the Discovery Bay region, south-western Victoria.** Australian Journal of Ecology 13:21-49.

Kemp, E.M. 1981. **Pre-quaternary fire in Australia. In : A.M. Gill** et *al.*. (eds). Fire and the Australian Biota.

Loyn, R.H. 1989. **Fire management and wildlife. In: L. Kelly (ed.).** Proceedings of the First Wildlife Management Conference Lorne. **Department of Conservation Forests and Lands, Melbourne.**

Loyn, R.H. 1989. **The management of duck hunting in Victoria—a review.** *AREIR* Report No *70*. **CFL, Melbourne.**

Lynch, J.J. 1941. **The place of burning in management of the gulf coast wildlife refuges.** The Journal of Wildlife Management 5:454-457.

Macarthur, **A.G.** 1966. **Weather and grassland fire behaviour.** Forest and Timber Bureau Leaflet No. *100*.

Mallick, A.U. **and Wein,** R.W. 1986. **Response of a** Typha **marsh to draining, flooding and seasonal burning.** Canadian Journal of Botany 64:2136-2143.

Meredith, C. W. 1984. Management of the Ground Parrot in Victoria—a report to the Fisheries and Wildlife Division. **Department of Conservation Forests and Lands, Melbourne.**

Meredith, C.W. 1988. Fire in the Victorian Environment: a Discussion Paper. **Conservation Council of Victoria, Melbourne.**

Meredith, C.W., **Gilmore, A.M. and Isles,** A.C. 1984. **'The Ground Parrot in south-eastern Australia; a fire adapted species?** Australian Journal of Ecology **9:367-380.**

Mihelsons, **H.,** Viksne **A., and** Medais, **A.** 1974. **The improvements of waterfowl nesting sites. In M. Smart (ed.).** International Conference on the Conservation of Wetlands and *Waterfowl*.

National Parks and Wildlife Division 1989. Draft Park Management Planning Manual. **Department of Conservation Forests and Lands, Melbourne.**

National Parks Service, Victoria 1985. Grampians National Park Draft Management Plan. Department of Conservation, Forests and Lands, Melbourne.

Noble, I. 1981. Fire ecology in semi-arid lands. In A. Heislers, P. Lynch and B. Walters (eds). Fire Ecology in Semi-arid Lands. National Parks Service, Melbourne.

Noble, I.R. and Slatyer, R.O. 1981. Concepts and models of succession. In A.M. Gill et al.. (eds). Fire and the Australian Biota.

Odum, E.P. 1971. Fundamentals of ecology. *W* B Saunders, Philadelphia.

Paijmans, K., Galloway, R.W., Faith, D.P., Fleming, P.M., Haantjens, H.A., Heyligers, P.C., Kalma, J.D. and Loffler, E. (eds) 1985. Aspects of Australian Wetlands. Division of Water and Land Resources, Technical Paper No. *44.* CSIRO Melbourne.

Pressey, R.L. and Harris J.H. 1988. Wetlands of New South Wales. In :A.J. McComb and Lake, P.S. (eds). The Conservation of Australian Wetlands. Surrey Beaty and Sons, NSW.

Pressland, A.J. and Keenan, F.J. 1985. Lignum control in channel country. Plant Protection Quarterly 1 (2).

Raison, R. J. 1980. A review of the role of fire in nutrient cycling in Australian native forests, and of the methodology for studying the fire-nutrient interaction. Australian Journal of Ecology 5:15-21.

Ronan, N. 1986. The hydrological effects of fuel reduction burning and wildfire at Wallaby Creek. MMBW, Melbourne.

Russell, J.S. and Isbell, R.F. (eds) 1986. Australian Soils: the Human Impact. University of Queensland Press, Brisbane.

Sant, G.J. and New, T.R. 1988. The biology and conservation of Hemiphlebia mirabilis *Selys (Odonata Hemiphlebia)* in southern Victoria. National Parks and Wildlife Division. Department of Conservation Forests and Lands, Melbourne.

Schlichtemeier, G. 1967. Marsh burning for waterfowl. In: Tall Timbers Fire Ecology Conference No 6.

Shay, J.M., Thompson, D.J. and Shay, C.T. 1987. Post-fire performance of *Phragmites australis* (Cav) Trin. in the Delta Marsh, Manitoba, Canada. Arch. *Hydrobiol. Beih.* August 1987.

Sculthorpe, C.D. 1967. The Biology of Aquatic Vascular Plants. Edward Arnold, London.

Smart, M. (ed.) 1974. International Conference on the Conservation of Wetlands and Waterfowl. International Waterfowl Research Bureau, Slimbridge.

Smith, L.M. and Kadlec, J.A. 1984. Effects of prescribed burning on nutritive quality of marsh plants in Utah. Journal of Wildlife Management 48 (1).

Smith, LM. and Kadlec, J.A. 1986. Habitat management for wildlife in marshes of the Great Salt Lakes. In : Transcripts of the *51st* North American Wildlife and Natural Resources Conference.

Specht, R.L. 1981. Responses to fires in heathlands and related shrublands. In A.M. Gill et *al.*. (eds). Fire and the Australian Biota.

Suckling, G. and Macfarlane, M. 1983. Fauna. In: E. Ealey (ed.). Fighting Fire With Fire. Monash University, Clayton

Thompson, D.J. and Shay, J.M. 1985. Effects of fire on *Phragmites australis* in the Delta marshes. Canadian Journal of Botany 63:1864-1869.

Thompson, D.J. and Shay, J.M. 1989. First year responses of a Phragmites community to seasonal burning. Canadian Journal of Botany 67:1448-1455.

Tolhurst, K. 1985. The Effects of Fire and Fire Prevention on Native Flora and Fauna (=published lecture notes). Department of Conservation and Environment Field Research Station, Creswick, Victoria.

Van Der Toorn, J. and Mook, J.H. 1982. Influence of environmental factors and management on Phragmites australis. Journal of Applied Ecology 19:477-499.

Vogl, R.L. 1967. Burning for wildlife in Wisconsin. Tall Timbers Fire Ecology Conference No 6.

6.8 APPENDICES

Appendix 6a Definition of terms

Community	a collection of sub-communities that have floristic and environmental affinities. The component sub-communities may be temporal stages of the same vegetation community.
Epicormic	a shoot or branch growing from a dormant bud on the trunk or branches of a tree, usually as a result of some damage to the tree.
Fire management	all aspects of fire prevention, pre-suppression, suppression and use of fire.
Fire pre-suppression	all those actions designed to minimise the impacts of fire and facilitate fire suppression.
Fire prevention	all action taken to minimise -the chance of a wildfire starting -the damage done by wildfire.
Fire suppression	all action taken from the detection of a wildfire to its control.
Herbaceous	lacking in woody tissue.
Lignotuber	a woody swelling, partly or wholly underground at the base of the stem of certain plants, notably eucalypts.
Monocotyledon	plants belonging to the group of flowering plants whose germinating seeds have one seed-leaf.
Paludification	the process whereby the accumulation of organic debris leads to the reduction in the depth of water in wetlands; the process results in the creation of marshes and peat swamps.
Prescribed burning	the planned application of fire under selected weather and fuel conditions so that fire is contained within a predetermined area and burns at a predetermined rate and intensity to achieve the desired objectives of the burn.
Rhizome	an underground stem.
Sub-community	an area of vegetation with similar floristic composition. Sub-communities can be recognised by their character species: species of plants which occur frequently and consistently within a sub-community.
Wildfire	any unplanned fire.

7 WETLAND RESTORATION

7.1 BACKGROUND

7.1.1 What causes degradation in wetlands?

Degradation of wetlands results from obstruction of the natural processes that shape them. This can take the form of disturbing agents that have been introduced to the site or natural disturbing agents occurring at unnatural frequencies or levels. The modification of natural water regimes is a frequent degrading process in wetlands. Such modifications include drainage, the diversion of water away from wetlands and the stabilisation of natural fluctuations in water levels. Removal of or damage to aquatic, amphibious and terrestrial fringing vegetation will result where the wetland is heavily grazed by stock or pest animals, or where fire occurs at unnaturally high frequencies. Deterioration in water quality can result from urban run-off, sewage or waste discharge, overgrazing, cropping, irrigation or deforestation within the catchment. Eutrophication results from increased nutrient inputs into the aquatic system and is a common degrading process in wetlands.

Degradation is not always readily discernible. It can take the form of lowering the diversity of both plant and animal species or a change in water quality and nutrient balance. Tall emergent macrophytes such as *Typha* and *Phragmites,* floating species such as *Azolla* and mat-forming amphibious species such as *Paspalum* are frequently out of balance in wetlands receiving high nutrient inputs, greater than normal water flows or which are subjected to a stabilised water regime. When out of balance, these plants frequently dominate at the expense of other species.

7.1.2 Restoration principles

Restoration of any natural system, including wetlands, is essentially achieved by applying ecological principles, and may be carrid out by manipulating the major site characteristics, ie hydrology, substrate and vegetation. Hydrology is by far the most important factor influencing wetland functions and is one site characteristic that the wetland manager can often influence. The duration, depth, flow, periodicity and physico-chemistry of water is directly linked to a number of wetland functions including groundwater recharge and discharge, flood control, erosion and shoreline stabilisation, sedimentation, nutrient cycling, food chain and habitat functions (Larson in Zelanzy and Feierabend 1987).

Where the original conditions can be re-established, restoration of a wetland may be achieved simply with minimum effort and a moderate risk of failure. Research has indicated, however, that leaving a wetland alone after removing artificial or disturbing influences does not necessarily lead to restoration. Success will depend on whether there is a local source of flora and fauna species for re-colonisation,

7.1.3 Wetland functions

Before beginning any restoration project, managers need to set the aims and establish the behaviour and effects of degrading agents. For instance, what is required of the wetland? What wetland 'functions' are to be restored, and to what standard? The success of wetland restoration projects is best measured by the wetlands ability to fulfil its natural functions. One of the greatest difficulties in undertaking the restoration of natural systems is the lack of knowledge of the processes that drive the system, and of the latitude the manager has in determining the appropriate management strategies to revive the system and re-establish its natural functions.

While it would be highly desirable to restore wetlands to their pre-European settlement condition, such an objective is likely to be impractical, as in most cases their pre-settlement condition will be unknown. Many freshwater wetlands restoration (and creation) projects have been reported as successes following the re-establishment of aquatic and fringing vegetation, and where this has created habitat for wetland vertebrates. While this may be a simplistic approach, it is likely to be the one most readily achievable and measurable. Once the wetland processes are restored, proactive management may be required to maintain them.

While many restoration techniques can be applied to wetland creation projects, the ability of artificial wetlands to mirror all of the functions of natural wetlands is not proven (Zelasny and Feierabend 1987). Wetlands are complex systems that cannot easily be replaced. The restoration of a natural wetland is preferred over the creation of a replacement wetland.

7.1.4 The need for restoration

Since European settlement there has been a substantial loss and modification of indigenous wetland habitats. While drainage has resulted in a direct and immediate loss of large areas of wetland habitat, unsympathetic and ill-informed land management practices has also resulted in wetland degradation. Degraded wetlands are no longer able to perform part or in some cases most of their natural wetland functions.

The recent increase in interest in wetlands has identified a pressing need for a management approach that reverses the current trends in wetland degradation. In many instances little is required to rejuvenate degraded systems and it may only require the elimination of a degrading agent or reversal of a process and the implementation of a sympathetic management regime to achieve a satisfactory result.

A major barrier hindering restoration projects to date has been the lack of knowledge. Significant advances have, however, been made in recent years in the understanding of wetland functioning and processes. With such information it is now possible for managers to attempt to restore the natural processes that shape the wetland environment.

7.2 THE ECOLOGY OF WETLAND VEGETATION

7.2.1 Introduction

Wetlands contain a wide variety of plant life forms including submerged and floating aquatics, emergent reeds and rushes, amphibious perennial and annual grasses, sedges, herbs and small to large shrubs and trees. On steeply sloping shorelines, wetland vegetation may occupy only narrow fringes, but on gentle slopes and within shallow depressions they can occupy vast areas.

Many wetland plants have a number of physiological adaptations which allow them to cope with an aquatic or amphibious life style and the stresses posed by periodic wetting and drying. It has been suggested that wetland habitats, while stable in the presence of regular change, are destabilised in the face of stable conditions (Denny 1985). Plants in communities subject to regular change or disturbance are frequently able to reproduce vegetatively, and this is common in wetland plant communities. This may involve random mechanical breakage of pieces of the plant or the abscission of morphologically distinct shoot or root propagules such as stems, rhizomes and tubers.

An understanding of the life history characteristics of the vegetation community indigenous to the site aids the development of a restoration strategy. Plants will frequently be represented in a wetland in one or more states: as a propagule in the seed bank, or as a vegetatively or sexually reproducing adult, or be locally absent or extinct. The life history of most wetland species will be revealed by observing wetland vegetation over time, with transition from one state to another. In particular, observing the wetland's two basic environmental states, dry and flood, and by an examination of the seed bank.

Life-history characteristics include:

- seed production;
- dispersal mechanisms;
- longevity;
- germination requirements;
- growth form and life span;
- environmental requirements; and
- growth rates under different environmental conditions.

7.2.2 The dynamics of wetland vegetation establishment

The Gleasonian model of vegetation dynamics states that all vegetation is in a state of constant change, and wetlands are no exception (van der Valk 1981). Wetland vegetation is constantly changing over time, both qualitatively (ie floristically), and quantitatively (ie species abundance and physical structure). This change can be rapid or very slow and almost imperceptible. Community change follows changes in the existing vegetation that result from damage by pathogens, herbivores and the actions of people, changes in the physical and chemical environment and from interactions between plants, eg invasion and establishment. Patterns of change can be described as succession (the establishment of new populations or the extinction of populations), maturation (the growth of individuals in established populations), and fluctuation (the changes to a population over time that are influenced by the varying and prevailing environmental conditions).

Although little studied in Australia, the major determinants of natural wetland vegetation composition and structure are considered to be:

- substrate depth, structure, pH and nutrient status;
- hydrology, eg distribution of water over space and time;
- water quality and chemistry, eg nutrient loading, turbidity, pH, electrical conductivity (EC) and temperature;
- wave action; and
- indigenous grazers.

It is well documented that the periodic wetting and drying patterns of wetlands are a major factor affecting productivity and vegetation establishment in wetlands (Neckles *et al.* 1990, Meeks 1969). Patterns of varying water depth will determine the character and structural variation of plant communities as well as other biotic communities in a wetland in both time and space (Dykjova *et al.* 1978).

Freshwater temperate wetland vegetation is typically strongly zoned, with particular plant communities forming concentric zones reflecting elevation (water depth) and following shore-line contours. These environmental gradients range from more-or-less permanent water pools through to areas subject to inundation over winter but may dry out significantly over summer. The width of the zones depends on the steepness of the gradient and the differences between the mean maximum and minimum water levels. In areas of more-or-less permanent water, the subAerged or emergent species are dependent on free water of a certain minimum depth, and may be regarded as true or 'obligate' aquatics. Species occupying shallower sites are adapted to periodic inundation, but survive summer drying, and may be termed amphibious. Some amphibious species show morphological differences in their submerged and emergent foliage.

Wetland species are able to colonise water bodies rapidly and many species will appear in ephemeral water bodies that form in depression following irregular flooding events. Zonation will usually only appear, however, in areas with regular and repeated flooding patterns (Thmida and Ellner as cited in Yen and Myerscough 1989).

7.2.3 The establishment requirements of wetland plants

Van der Valk (1981) has developed a classification model for wetland plants based on three life history characteristics, life span, propagule longevity and propagule establishment requirements. By combining these three life history features, van der Valk (1981) determined 12 basic wetland life history types. This model allows the establishment requirements of wetland plants to be determined.

Wetland species fall into three adult lifespan categories, annuals, perennials and vegetatively reproducing perennials:

1 Annuals include true annuals (mud-flat colonisers) as well as perennials that behave as annuals in the face of seasonal drying.

2. Perennial species with or without vegetative reproduction that have a limited life span are classified by van der Valk as perennials.
3. Perennial plants with vegetative reproduction that do not have a definite life-span are classified as vegetatively reproducing perennials.

The propagules of wetland plants can also be classified into two classes also based on longevity:

1. Dispersal-dependent species have short-lived seed and can only become established on a site if a source of propagules exists nearby.
2. Seed bank species however, have long-lived seeds that persist in the wetland substrate where they accumulate over time. Species in this group become established whenever conditions become suitable.

Vegetatively reproducing perennials are reported to be by far the most common type of plant in wetland communities. Van der Valk (1981) cites a study by Kadlec and Wentz which indicates only 14% of North American aquatic and wetland species are annuals; the remaining 86% are perennials, and of these 90% are vegetatively reproducing perennials. Van der Valk (1981) also suggests that the majority of annuals are dispersal dependant with short-lived seed and that submerged and free-floating aquatics survive dry periods as seed in the seed bank.

As stated above, plants can become established in a wetland from either seed or vegetative propagules, and may do so either when water levels are falling, or in standing water depending on their germination and establishment requirements. Each of these groups can be further subdivided into shade-tolerant species, which germinate and establish within stands of existing vegetation, and shade-intolerant species, which can establish only in areas free of vegetation. The available literature suggests that the majority of annual and perennial emergent species become established following drawdown in areas free of existing vegetation.

This scheme of establishment is well illustrated by two common wetland perennials. *Typha* spp. reproduce vegetatively when there is standing water, and become established from seed (which may be present in the seed bank) on mud flats in areas free of vegetation. *Phragmites australis,* on the other hand, reproduces vegetatively and has seeds that germinate on mud flats where parent plants have recently shed seed.

Establishment from seed

While establishment from seed is considered to be the secondary form of vegetative establishment in wetland communities, it can nonetheless be significant in degraded wetlands where many species may only be present as soil-stored seed. Weinhold and van der Valk (1989) suggest that recruitment from seed was significant in the restoration of North American prairie pothole wetlands. Recruitment from seed is also important for particular plant groups such as mud-flat annuals. The accumulation of seed in the substrate can result in the development of substantial seed reserves of some wetland species (Leck and Graveline 1979).

High soil moisture, moderate to high temperatures, exposure to unfiltered light and low soil conductivity are considered to favour the germination of the seeds of many wetland species (Kadlec 1962, Kiddle 1987, Smith and Kadlec 1983, van der Valk and Davis 1978, van der Valk 1981, Welling et al. 1986). Germination and establishment of propagules may follow the lowering of water levels and exposure of the substrate. Germination of some species will also occur where seed is completely immersed, and this is particularly the case for submerged, free-floating and rooted floating aquatics. Some species also have an absolute requirement for shifts in temperature.

Rates of recruitment from germinating seed will be influenced from year to year by varying environmental conditions. A Canadian study of the Scirpus, Typha, Phragmites and Scolochloa-dominated Lake Manitoba delta marsh found that variations in environmental conditions, while affecting the numbers of individuals germinating, did not stop any particular species from germinating.

High soil salinities are known to inhibit germination of many species. This is more a factor of osmotic inhibition than of seed death, and seed germination will follow the return of more favourable conditions (Smith and Kadlec 1985). The maintenance of low level flooding or at least a regular flooding to flush the site is likely to provide more suitable conditions for germination on saline sites (Smith and Kadlec 1983).

Wetland seed banks

In many freshwater wetlands, plant recruitment from seed occurs primarily following a lowering of water levels (drawdowns). Typically, most recruitment following a drawdown comes from soil-stored seed (Smith and Kadlec 1983).

A knowledge of the seed bank will aid the understanding of the responses of wetland vegetation to water level manipulation and the removal of artificial disturbance agents. Seed banks have been used to predict the composition of drawdown-induced vegetation in north American wetlands (Leck and Graveline 1979, Smith and Kadlec 1983). The relative abundance of soil stored seed is not, however, necessarily useful in predicting the relative abundance of seedlings that appear following drawdown (Smith and Kadlec 1983, Welling et al. 1988), nor does it reflect the relative abundance of the extant or extinct vegetation of the site (Smith and Kadlec 1983 : 679). The seed bank can contain the seed of more species than are present on the site as adults, and not all the species present will be represented in the seed bank. The presence of soil stored seed in wetland soils does, however, indicate that there is potential for substantial natural regeneration of wetland vegetation from even drained wetlands.

The presence of seed in the seed bank is influenced by a number of factors, including:

- the presence of species producing long-lived seed;
- the nature (structure) of the existing vegetation and its ability to trap seed;
- the prevailing physical and chemical conditions;
- the nature of the site and its suitability for seed accumulation; and
- seed predation (very little is known about seed predation in wetlands).

Seed longevity and dormancy may be affected by soil moisture, temperature and soil chemistry.

Wind and water are effective dispersal agents for the seed of wetland species. Seed distribution is also influenced by the physical barriers that trap seed. Seed accumulates on the shoreline as a result of water movements depositing seed along drift lines. Emergent shoreline vegetation is also very effective in trapping both water and wind dispersed seed (Smith and Kadlec 1985). Pederson and van der Valk (undated) recorded few seeds in seed traps located in open deep water.

In one study, seed densities in the top 10 cm of soil of a North American freshwater marsh, ranged from 6405 to 32400 seeds/m^2 (Leck and Graveline 1979). The timing of seed bank sampling is important where annuals form a significant proportion of the site's flora. As would be expected, seed density decreases gradually with soil depth (Leck and Graveline 1979).

Seed banks can provide a significant source of propagules that can lead to plant and cover establishment faster than revegetation by artificial means. The presence of a substantial seed bank in the shoreline zone suggests that drawdowns are likely to be the best option for promoting emergent vegetation (Pederson and van der Valk undated).

As could reasonably be expected, species richness and seed density in the seed bank decline with increasing duration of drainage. A study of North American prairie pothole wetlands examined a range of wetlands that had been permanently drained for up to 70 years (Weinhold and van der Valk 1989). It revealed that 60% of the species present in the seed banks of existing wetlands were present in wetlands that had been drained for 20 years, these included species of *Alisma, Eleocharis, Juncus* and *Scirpus; Juncus, Ranunculus* and *Scirpus* persisted after 30 years; *Carex, Polygon=* and *Rorippa* persisted after 40 years; and *Echinochloa, Polygonum, Rumex* and *Typha* persisted 70 years after drainage. As drained wetlands have the potential to hold some water during wet years, it is likely that some species do germinate and reproduce, thus the longevity of seed may be shorter than the data from this study suggests. Seed longevity would also be reduced by cultivation. This study suggests that vestigial seed banks can play a significant role in the restoration of drained wetlands, and that wetlands drained for less than 20 years may have seed banks that contain viable seed of many wetland species, and consequently these wetlands are good candidates for restoration.

7.3 PLANNING RESTORATION PROJECTS

7.3.1 Introduction

The principal aim of restoration projects should be to return the wetland to as near as practical to its pre-disturbance condition.

The following management principles are suggested as the basis for any decisions or actions relating to the restoration of wetland habitats:

1. Restoration should attempt to return wetlands to a condition that approaches as closely as possible their pre-disturbance condition.
2. Restoration should, wherever possible, utilise natural means to achieve the aims of the project.

3 A successful restoration project will be based upon a well thought out action plan.

Section 7.3.2 outlines the procedure to be adopted when developing a restoration plan. The application of these procedures to a specific wetland will be influenced by the nature and degree of degradation, and the existing and potential value of the site to be restored. Not all wetlands will need to be actively restored. In many instances the removal of the degrading agents will allow natural processes to proceed. None-the-less, some management strategy will need to be developed to ensure a sound basis for decision making and continuity of management approach.

7.3.2 Developing a restoration plan

Establishing restoration priorities

The first step in planning restoration projects is to gain a comprehensive knowledge of the wetlands of the region or planning area. To fully conserve the region's wetland biota and wetland functions and protect high value sites it is necessary to determine the types and mix of wetlands that require restoration.

The criteria for deciding the priority for restoration projects should include:

- the conservation value of the wetland; has it been assigned a high value status?
- is it a type well represented in the region?
- is it part of a system of wetlands where the component wetlands of the system are important as flyways or serve as drought refuge?

What the plan should say

Once a regional priority has been determined, individual wetlands in need of restoration can be targeted and a plan of restoration devised.

The restoration plan should establish:

- the aims and objectives of the project, and where possible what wetland functions need to/can be restored;
- to what standard the various functions, eg floristics, vegetative cover/structure, water regime, habitat types, are to be restored;
- the site characteristics, eg what environmental and disturbance factors operate to influence the functioning of the site, the opportunities and constraints of the site;
- what biological and engineering actions are required to meet the restoration objectives. These need to be translated into designs and methods;
- a works program detailing the sequence and timing of implementation and the costing of the actions;
- the responsibility for implementation and the long-term management requirements and responsibilities.

One of the greatest difficulties in planning and implementing restoration projects is the lack of site-specific and system-wide knowledge. More detailed data will enable better and more flexible responses to be devised. The planner needs to understand the site and the factors that influence it. Factors to be considered include:

- the hydrology;
- the natural, existing and previous vegetation patterns including the presence of rare or threatened species;
- topography;
- the requirements of the species known to inhabit or to be encouraged to the site;
- the disturbing agents present; and
- the changes that have occurred in the catchment.

Site information can be obtained by examining remnant vegetation patterns, old topographic maps and aerial photos, from discussion with adjoining landholders, by recording the site's characteristics and by observing the processes that operate on the site and other physically and hydrologically similar sites in the local catchment. Wetlands are products of continuing environmental processes and are themselves changing and developing in the face of these processes.

Restoration objectives will usually be based upon some knowledge of the wetland's functions (ie the role of the wetland in the environment), and it may include some anthropogenic as well as ecological functions. The former functions may include flood mitigation, groundwater recharge or discharge, provision of habitat for a particular species or a group of species and recreation and landscape values. Some decisions relating to the objectives or outcomes of the project may be based on the site conditions of similar but intact/undisturbed wetlands in the region.

Once the site's functions have been identified, the functions to be restored should also be able to be identified, and the latter can then be translated into restoration objectives. For example 'provide a water regime that creates a wetland with an average depth of 0.5 metres and an annual average water duration of eight months, with early summer drying'.

Given the limited knowledge and practical experience in wetland restoration in Australia, all restoration projects will be to some degree experimental. For this reason, an adaptive or incremental approach may be appropriate for restoration projects that are in any way staged over time or complex in nature. Where this approach is adopted, the implementation of actions will proceed slowly, and the effects of each action or stage of the project are determined before the next stage proceeds. Subsequent actions can then be modified or adapted depending on the outcome of the previous stage. A monitoring program to record the progress and success of the works, and the nominated field officer position responsible for carrying out that monitoring, should be identified in the plan.

There is also a need to determine the need for and type of maintenance that will be required when the works have been completed. Ideally the project should aim to return the site to as near a natural state as possible and so alleviate the need for high level maintenance.

Planning for restoration should be incorporated in an overall plan of management, as restoration is likely to only one of a number of actions required to manage the site to be restored appropriately.

7.3.3 Pre-planning investigations

Seed bank investigations

As previously stated, wetland seed banks can provide an important source of propagules for restoration projects. A knowledge of the seed bank may be important in determining the response of the area to a particular restoration strategy, and the need to look to other techniques to successfully restore the sites vegetation.

The following methodology to establish the species and relative abundance of seeds present in the seed bank and determine the likely response of the site to the proposed restoration strategy and the need to adopt other than natural revegetation options has been adopted from North American seed bank studies (Leck and Graveline 1979, 1987; Pederson and van der Valk 1984; Smith and Kadlec 1983; Weinhold and van der Valk 1989). The method and level of detail adopted for a particular study will depend on the available monetary resources.

Sample collection:

i Collect soil samples below the normal (average) high water mark, following late spring—early summer drying.

ii Collect at least 10 replicate soil samples of 10 x 10 x 2 cm at one metre intervals along transects parallel and perpendicular (to above the mean maximum high water mark) to the shoreline.

iii Samples to be kept separate and the position of those collected along the perpendicular transect to be noted for each sample. Store in plastic bags and trays for transport.

Greenhouse germination:

i Remove sticks, roots, rhizomes and other extraneous materials from soil samples.

ii Soil conductivity (salinity) should be determined and monitored using standard techniques.

iii Spread each sample to 1 cm thick over a moistened 2 cm layer of perlite in 20 x 20 x 4 cm trays perforated to allow for drainage.

iv Trays should be placed in a greenhouse under conditions of natural light, normal photoperiod and a temperature range of 18-35 °C.

v Half of the samples from each transect batch should be kept saturated and irrigated with distilled water; the remaining samples to be immersed and remain flooded in 3-4 cm of distilled water.

vi Samples to be treated bi-monthly with a dilute solution of N:P:K fertiliser.

vii Seedlings to be monitored at weekly intervals and seedlings removed as soon as they are identifiable.

viii Soil samples should be maintained for up to 12 months to fully exhaust the viable seed stock.

ix Greenhouse germination can be compared to *in-situ* germination by monitoring field quadrats.

7.4 TECHNIQUES FOR RESTORING WETLAND HABITATS

7.4.1 Introduction

Most wetland ecosystems exist because certain plants adapted to aquatic and amphibious conditions establish and grow where such conditions prevail, and it is the interaction between vegetation and water that creates wetland habitat. Thus, in any wetland restoration project where the aim includes the return of some natural biological functions, the restoration of wetland vegetation could be regarded as second only to the restoration or management of water.

Several methods can be employed to restore wetland vegetation. The one chosen will depend on the aims of the project, the time scale, the particular plant species to be restored to the site and the available dollars. The methods which turn the balance back in favour of natural wetland processes and are less interventionist are preferred. While establishment may be slower by such means, the risk of failure is reduced. Such an approach is also less costly and this may enable more projects to be undertaken.

General Guidelines:

i Natural wetland processes should be permitted and encouraged to operate wherever possible.

ii The general approach to revegetation will be one of encouraging plant establishment by non-interventionist and natural means.

iii Where active means of revegetation are used, such as planting of nursery stock or transplanting from other sites, these will utilise only indigenous material of the local provenance variety, where possible from within the wetland, or where this is not possible from within the catchment.

iv Any methods employed to revegetate a wetland should not be a disturbing agent in its own right.

7.4.2 Understanding and mitigating the degrading processes

No restoration project can succeed if the processes that have degraded the wetland are still operating. Degradation processes will include drainage, modification of water supply, eutrophication, stock grazing, cultivation, salinisation, water pollution, pest plant infestation and unnatural fire regimes.

The removal of disturbing agents is an essential step in re-establishing conditions under which vegetative recovery will occur. In some instance restoration can be achieved solely by removing the degrading process or agent and allowing natural processes to continue. The response of wetland vegetation to the removal of stock grazing, for example, is evident in many areas across Victoria. Faber (1983) reported that tidal marsh communities will regenerate naturally on sites where natural processes operate and conditions approximate the natural prevailing conditions for such communities. Research has indicated, however, that leaving a wetland alone after removing artificial or disturbing agents will not necessarily lead to restoration. The degree and rate of recovery will be influenced by a number of factors, including the extent and nature of the disturbance, the prevailing environmental conditions, the effects of unknown future natural disturbance events and on the control or prevention of new/additional disturbance events and agents (eg pest plants and animals) and, importantly, if there is a local source of flora and fauna species for recolonisation. It is tempting to require an immediate result, particularly when the success of the project needs to be demonstrated to the community funding agent. Whatever the approach, some monitoring of the responses to the removal of the degrading process will be necessary so that a proactive approach can be implemented as and when required.

The objective is to eliminate or substantially reduce the negative effects of disturbing agents to facilitate the recovery of wetland vegetation.

When restoring wetlands disturbing agents should be identified and removed or their effects minimised by careful management. These disturbing agents may include domestic stock and feral grazers such as rabbits and goats, exotic plant species that are invading, or have the potential to invade natural wetland communities, inappropriate recreational, commercial or other use of the area, fires of unnatural frequency or intensity and stabilised or otherwise altered water regimes.

Modification of hydrology

Modification of natural hydrological regimes and processes is one the most common degrading process affecting Victorian wetlands. While it is relatively easy to drain or divert water from or into a wetland, the restoration of natural water regimes and the manipulation of water in wetlands is likely to be a difficult task, and a major obstacle in some restoration projects.

The restoration of the natural watering patterns may be all that is needed to restore some wetlands. Marsden (1986), in a review of a pilot restoration project in western Minnesota (USA), claimed considerable success in wetland restoration by simply installing drainage ditch plugs or tile blocks to provide an 'optimum water depth'. While in theory this approach seems a simple one, in practical terms it can be difficult and at times costly to achieve. Restoring water regimes, including the natural water flows to and from wetlands, can have major implications for surrounding land use. None-the-less, the importance of restoring or at least controlling water regimes cannot be over estimated.

Before wetland managers can begin the process of restoring the wetland, they need to understand the link between wetland functions and hydrological processes. Wetlands are dynamic environments whose long term stability and productivity are linked to wetting and drying cycles. All wetland types are subject to some sequence of wetting and drying, be it diurnal with tidal movements or regular, irregular, partial or complete seasonal (summer) drying. In its review of wetlands of the Murray Valley, the South Australian River Murray Wetlands Working Party (1989) discussed the opportunities and options for improving existing wetland habitat. The review found that permanent wetland habitat had increased, and the Working Party recommended the regular drying of now permanent wetlands as an aid to wetland health and to provide a range of wetland habitats. This review recommended two to four months drying during autumn to late summer every two to three years for selected wetlands, taking into account seasonal conditions.

Where the original watering patterns (regimes) of wetlands have been altered, these can be determined from:

- examining remnant vegetation patterns of the site;
- consultation with adjoining landowners;
- examining gauging station records to determine flood frequency, where wetlands are on the flood plain of a major stream;
- a knowledge of the water regimes of similar wetlands in the catchment; and
- air photos.

Watering patterns can also be determined by basin morphology and drainage patterns within the catchment.

Water quality

The effects of nutrient inputs from human sources and rising salinity are of particular concern as degrading processes in wetlands. The State Environmental Protection Policy—Waters of Victoria (EPA 1988) (Victorian Government Gazette 26 February 1988) sets out specific limits for various water quality indicators and objectives for five broad land-use classes—aquatic reserves, parks and forests, estuarine waters, coastal waters and general surface waters. The policy is applicable to all surface waters of Victoria, including coastal waters, but not groundwater, except where varied by conditions of separately declared. These limits can be used as a basis for managing point source discharges to minimise nutrient inputs and establish water quality management standards. Very little information is documented on the water quality requirements for wetland plant establishment (see below), but the significance of water quality as an influence on vegetation establishment should not be under-rated. Low pH and high salinities have been reported to inhibit plant establishment at Seaford and Westgate Park wetlands (Muir pers. comm., Sharp pers. comm., Melbourne Water).

7 RESTORATION

Eutrophication

Eutrophication or nutrient enrichment results primarily from inputs of nutrient rich waste waters such as sewage effluent, urban stormwater and runoff from agricultural land (Bowmer 1981, DCEWA 1980, Royle 1987). The eutrophication of wetlands promotes the growth of aquatic plants and an increase in the organisms and processes responsible for decay. This increase in plant growth and/or biological activity can cause a number of problems. It leads to algal blooms that can pose threats to wildlife and humans, macrophyte blooms that can modify indigenous habitats and block water management structures, it can deplete oxygen supplies, kill fish and cause physio-chemical changes in water quality. Bowmer (1981) reports that eutrophication can also lead to the decline of submerged macrophytes as algal growth forms a thick layer over leaves. Royle (1987) estimates the costs associated with the eutrophication of Australian wetlands and waterways to be between $10 and $50 million.

Phosphorous and to a lesser extent nitrogen appear to be the most important nutrients involved in eutrophication (Bowmer 1981). Phosphorus is frequently a limiting element in indigenous systems, and phosphorous supplies are dominated by discrete concentrated sources associated with human activity. The significance of phosphorous inputs from soil erosion may be underestimated, however, as very high levels of phosphorous have been recorded in Australian waters downstream of pasture, cereal areas, and in farm dams in orchard and grazing catchments (Bowmer 1981). Increased productivity generally requires an increase in both nitrogen and phosphorous, but only one of these needs to be limited to reduce productivity. Nitrogen is generally available from diffuse sources throughout the catchment. It is frequently less limiting, as blue-green algae are able to fix atmospheric nitrogen when aquatic nitrogen levels are low. Nitrogen is also readily lost to the atmosphere under certain chemical conditions. This ready exchange of nitrogen between the air and water means that the impacts of nitrogen inputs are difficult to assess.

Eutrophication is more likely:

- where accumulation of nutrients can occur;
- in low flow periods; and
- where low N:P ratios occur (Ecological Horticulture 1989).

The restoration of eutrophic systems involves controlling nutrient inputs and maximising nutrient utilisation or export until acceptable nutrient levels have been reached. It is generally accepted that the most efficient way of reducing nutrient input into aquatic systems is to control point source discharges. The relative and cumulative significance of non-point sources such as agricultural run-off also warrants some control.

Such control can be achieved by:

- diverting nutrient-laden effluent away from wetlands;
- removing nutrient from effluent before it enters wetlands;
- improving agricultural practices, including methods and rates of applying fertiliser, and improving stock management;
- establishing appropriate vegetative buffers around wetlands; the State Pollution Control Commission (NSW) recommended a minimum 20 metre indigenous vegetation buffer around wetlands to act as an infiltration area for surface runoff.

Where wetlands are already eutrophied, a reduction in nutrient input combined with the following has been suggested by Bowmer (1981), DCEWA (1980), Robinson (1988) and Royle (1987) as a means of restoring the nutrient balance of the site:

- removing nutrients by flushing or dilution by adding low-nutrient water;
- removingor isolating high nutrient sediments by dredging;
- phosphorous inactivation by chemical means (Alum);
- removing nutrients through macrophyte uptake and subsequent harvesting.

It is now well documented that wetland macrophytes can take up and retain significant nutrient loads, and the *[X]* settle suspended solids (Boutin 1987, Ecological Horticulture 1989, Reddy and De Busk 1987, State Pollution Control Commission NSW). This is possible as these plants can assimilate nutrients in excess of their needs, slow water flows, trap sediments and enhance microbial activity and immobilisation of phosphorous through aeration (Ecological Horticulture 1989). Macrophytes including *Phragmites australis, Typha* spp., *Eleocharis sphacelata* (Tall Spike-rush), *Schoenoplectus validus* (River Club-sedge), and *Myriophyllum* spp. (Milfoil) have been documented to be effective in reducing the concentrations of total nitrogen and phosphorous and reducing suspended solids and turbidity (Mitchell 1978, Synot and Brown 1985, Finlayson and Chick 1983, Boutin 1987). As a result there is growing interest in the use of wetland macrophytes in both natural and built wetlands to treat nutrient and sediment enriched waters. Nutrient uptake by macrophytes may decrease with time, however, so macrophyte beds may need to be 'renewed' (Boutin 1987, Mitchell 1978). Reddy and De Busk (1987) reported that emergent macrophytes in artificial wetlands used for waste-water treatment need to be harvested to enhance N, P and heavy metal removal, and enhance oxygen transfer to the root zone. Where wetlands have a role in managing water quality, long term vegetation management will be required if the wetland is to continue to fulfil this function (State Pollution Control Commission of NSW undated).

Salinity

The management of most wetlands still depends to some extent on controlling the activities that affect water quality and quantity within the catchments that feed them. In the case of salinisation, management depends on control over the extent of vegetation clearing that is carried out, and the acceptance of land management techniques which minimise groundwater recharge and discharge, prevent or retard salinisation, or rehabilitate salinised sites.

The salinisation of wetlands is best controlled or mitigated by controlling or influencing land-use within the catchment, through the development of whole catchment management plans, and whole farm planning. Wetland managers should contribute to the development of these plans and policies wherever possible to ensure that wetland values are considered in such plans or schemes.

The Centre for Stream Ecology (CSE 1988) has reviewed the effects of saline discharge on wetlands. The known salt tolerances of various components of the freshwater aquatic biota, and the effects of salinity on wetland ecosystems are summarised below.

Macrophytes

- A large proportion of the macrophytes associated with Victorian wetlands are salt sensitive, with salinity increases up to around 1000-2000 mg/L expected to result in lethal effects. It is likely that sub-lethal effects are operating below this level, but the extent is unknown.
- Large variations in salt sensitivity occur between species and between populations of the same species from different locations.

- Salt sensitivity can differ between the seeds, seedlings and mature plants of an individual species.
- Factors such as rate of salinity increase and temperature fluctuations in the water body will influence the actual salinity level that is toxic to aquatic plants.
- Field studies show that diversity of macrophyte species decreases as salinity levels increase.

Invertebrates

- Invertebrate species appear amongst the most sensitive of the freshwater animals to increases in salinity, with adverse effects likely to occur in some species at salinities in excess of 1000 mg/L.
- The available data suggests that the most sensitive invertebrate animals are from three groups: simple multi-cellular animals, insects and molluscs.
- The crustaceans appear to be the most salinity tolerant of the invertebrates; within this group, some species are quite salt sensitive.

Fish

- Adult Victorian freshwater fish species appear to be quite tolerant of salinities up to ca. 10 000 mg/L.
- The information available on the sensitivity of critical life stages of fishes to salinity suggest that the sperm is most sensitive, and may provide a conservative estimate of a species salinity tolerances. The larval stages may be more sensitive to salinity than adult stages. Fish eggs appear to be more tolerant of salinity increases.

Amphibians

- No data exist on the salinity tolerances of adult frogs. Overseas studies suggest that adult frogs should be able to tolerate salinities up to ca. 10 000 mg/L, but only for a limited time.
- Tadpoles and egg masses may be sensitive indicators of the biological effects of salinity in wetlands.

Reptiles

- Freshwater turtles *(sic)* are the reptiles most at risk from salinity increases in lowland wetlands.
- Indirect evidence suggests that Australian freshwater turtle *(sic)* species with functional salt glands may be able to cope with salinities up to 5000 mg/L.

Water birds

- Salinity tolerances vary greatly between the different water bird species.
- Many species are able to feed in saline waterbodies, but must have freshwater nearby to drink.
- Many water birds are dependent upon macrophytes (for nesting and cover) and invertebrates (for food). Both these groups are likely to be adversely affected at salinities well below those directly affecting water birds.

Mammals

- Australia's only strictly freshwater mammal is the platypus. No information exists on its salinity tolerances.

The precise effects of salinity increases are uncertain due to the lack of data on many potentially salt-sensitive freshwater plants and animals and a lack of studies on the long-term and sub-lethal effects of salinity. Wetlands, being less flushed than rivers and streams, are likely to have greater increases in salinity if saline water discharges into them. In some wetland systems, there will be a cumulative effect over time (CSE 1989).

On sites with high sediment salinity, the effects of salinity on vegetation can be minimised by low-level continuous flooding during the growing season. A complete drawdown or drying should be avoided on such sites.

Grazing

Refer to Livestock Grazing in chapter 5 of this Manual.

Pest plants and animals

Australian aquatic systems have been invaded successfully by introduced plants and animals. In the absence of natural population checks, such as disease and parasites, many of these have established rapidly. Several aquatic plant species have invaded some aquatic systems so successfully they have been described as biological explosions (Arthington and Mitchell 1986). Such plants are able to outcompete their indigenous equivalents, adversely affect wildlife habitat, limit the use of water by humans, adversely affect water quality and increase silting and flooding effects (Sainty and Jacobs 1981).

The need to control pest species will depend on the species involved and the competitive threat it poses to re-establishing indigenous species. Pasture grasses for example, while not obviously a threat, can effectively exclude re-establishing indigenous species. There may be situations where introduced plants provide an important part of the wetland habitat in the absence of indigenous species, and control in such situations needs to be tempered. The management options in such cases are (i) retain the species but control spread and/or (ii) a gradual replacement with an equivalent indigenous species over time. Situations such as this are now common, and Blackberry, *Phalaris* and Spiny Rush frequently provide significant habitat in degraded wetlands (Sharp[9] pers. comm.). The need for weed control may diminish over time as re-establishing vegetation creates a closed sward limiting opportunities for weed establishment.

Introduced plant species

In Australia, the majority of serious aquatic weeds are introduced plants (Sainty and Jacobs 1981). Depending on the literature consulted, and the definition of what is aquatic, it is reported that up to 55 species have been introduced to Australian waters; fewer have established themselves as part of this continent's wetland flora (Arthington and Mitchell 1986). A larger number of aquatic plants are reported to be weeds in some situations (Mitchell 1978), but these include a number of native species that interfere with water management activities. At present, most of the problematic weeds are restricted to the warmer waters of northern Australia.

---

[9] K. Sharp, Victorian Wetlands Trust.

Introduced plants that have the capacity to become weeds in wetlands share several common features, and those species with the capacity for rapid (frequently vegetative) reproduction and efficient dispersal are likely to be most successful. Dispersal is a vital attribute, since in its absence a plant is likely only to become a locally established 'escape' and not truly naturalised. The importance of humans as a significant dispersal agent must not be overlooked (Arthington and Mitchell 1986). Successful biological invasions often occur where there has been some disturbance and consequent displacement of indigenous species. Overgrazing, water stabilisation, eutrophication, high fire frequency and soil/substrate disturbance will aid the establishment and in some instances promote weedy species.

Several species that were previously regarded as native are now considered introduced, eg _Cotula coronopifolia_ (Water Buttons) and _Paspalum distichum_ (Water Couch) (Ecological Horticulture 1989, Ross 1990). The latter is known to be a problem under stabilised water and high nutrient situations (author's observation); while the former may not present a problem, its use in restoration/creation projects should be avoided.

At least three genera of aquatic plants are present in Victoria as native and exotic species which are not easily distinguished, eg _*Typha latifolia_—_Typha domingensis_ and T. _orientalis_, _*Alisma lanceolatum_—_Alisma plantago-aquaticum_ and _*Myriophyllum aquaticum_—_Myriophyllum_ spp. (Ecological Horticulture 1989).

The seriousness of the threat posed by introduced plants to Victorian wetland habitats is not clear. Table 7a shows introduced species that have been recorded, are naturalised or are capable of invading Australian wetlands (Arthington and Mitchell 1986, Cunningham _et al._ 1981, Ecological Horticulture 1989, Ross 1990, Sainty and Jacobs 1981, South Australian River Murray Wetlands Working Party 1989, Frood in prep.).

There will be many plants that are weeds of the fringing vegetation or surrounding dryland communities. All introduced species, including non-indigenous natives are undesirable in areas managed for nature conservation. It will not, however, be practical to control most species.

Table 7a Introduced plant spp. found in Australian wetlands

Abutilon theophrasti	Swamp Chinese Lantern
Agrostis spp	Blown Grass
Alisma lanceolatum	Water Plantain
Altemathera philoxeroides	Alligator Weed
Anthoxanthum odortatum	Sweet Vernal Grass
Aponogeton distachyos	Cape Pond Lily
Arundo donax	Giant Reed
Aster subulatus	Bushy Starwort
Brachiaria mutica	Para Grass
Ca&riche hamulata	Starwort
Callitriche stagnalis	Water Starwort
Cortaderia selloana	Pampas Grass

Cotula coronopifolia	Water Buttons
Crataegus monogyna	Hawthorn
Cyperus eragrostis	Umbrella Sedge
Cyperus involucratus	
Cyperus papyrus	Papyrus
Echinochloa oryzoides	Hairy Millet
Egeria densa	Dense Waterweed
Eichhomia crassipes	Water Hyacinth
Eleocharis sp.	
Elodea canadensis	Canadian Pondweed
Glyceria declinata	Glaucous Sweetgrass
Glyceria maxima	Reed Sweetgrass
Holcus lanatus	Yorkshire Fog Grass
Hydrocleys nymphoides	Water Poppy
Hydrocotyle bonariensis	
Iris pseudacorus	Yellow Water-iris
Juncus acutus	Spiny Rush
Juncus articulatus	Jointed Rush
Juncus bulbosus	Bulbous Rush
Lagarosiphon major	Lagarosiphon
Leersia oryzoides	Leersia
Leontodon taraxacoides	Lesser Hawkbit
Lilaea scilloides	Lilaea
Lolium perenne	Perennial Ryegrass
Lolium rigidum	Wimmera Ryegrass
Ludwigia palustris	Marsh Water Primrose
Ludwigia peruviana	
Myriophyllum aquaticum	Brazilian Water Milfoil
Nassella neesiana	
Nuphar lutea	
Nymphaea alba hybrids	Water Lily
Nymphaea capensis	Water Lily
Nymphaea flava	Water Lily
Nymphaea tuberosa hybrids	Water Lily
Nympheae mexicana	Water Lily
Panicum repens	Torpedo Grass
Paspalum distichum	Water Couch
Phalaris arundinaceae	Reed Canary Grass
Polygonum orientale	Prince's Feather
Polypogon monspeliensis	Annual Beardgrass
Pontederia cordata	Pickerel Weed
Ranunculus muricatus	Sharp Buttercup
Ranunculus repens	Creeping Butterwort
Ranunculus scleratus	Celery Buttercup
Rorrippa microphylla	One-row Watercress
Rorrippa nasturtium-aquaticum	Watercress
Rosa rubiginosa	Sweet Briar
Rubus procerus	Blackberry
Rumex cripus	Curled Dock
Sagittaria engelmanniana	
Sagittaria graminea	Sagittaria

Salix spp	Willow
Salvinia molesta	Salvinia
Schoenoplectus prolifer	Broadleaf Water Parsnip
Sium latifolium	
Thalia dealbata	
Typha latifolia	Cattail/Reed-mace
Veronica anagaffis-aquatica	Blue Water Speedwell
Veronica catenata	Pink Water Speedwell
Zantodeschia aethiopica	Arum Lily

Native plant species

Several native wetland species have the capacity to act as weeds, ie to exclude other species by competition, in disturbed wetlands. Two life forms in particular may present problems, the tall rhizomatous perennials which form large monospecific stands, eg Cumbungi *(Typha* spp.) and Common Reed *(Phragmites australis),* and unattached floating plants that form dense mats on the water surface, eg Pacific Azolla *(Azolla filiculoides).* Problems caused by these plants are frequently symptoms of a greater problem, such as modified water regimes (frequently stabilised) and increased nutrient inputs. These species have the capacity for rapid colonisation and expansion, and are frequent colonisers of channels, drains and around water control structures where they earn their weedy reputation and are widely controlled. There is a common perception in the community and amongst some wetland managers that these species, and particularly the former, are weeds wherever they occur. This is not the case, and all are widespread members of Victoria's wetland flora.

Weed control

The control and management of wetland weeds should be based on an understanding of their life history and ecology and research into the field of weed biology and control needs to be encouraged.

One of the major factor to be considered when proposing weed control is usually cost. The cost of the proposed control measures must be set against the expected benefit. The short-term view only considers the immediate costs and benefits, but short-term action may save considerably greater expenditure in the future.

Weed control will usually be effected by a combination of three methods. The use of any particular method will be strongly influenced by the site, the prevailing conditions, the weed to be controlled and its life stage.

1. **Good Management:** Prevent or reduce the spread of weeds by adopting sound hygiene practices, eg wash down machinery and vehicles after visits to weedy sites.
2. **Mechanical Control:** This form of control includes cultivation, slashing and mowing and burning. Specialised equipment is frequently required for the control of aquatic weeds, and labour costs can be high.
3. **Chemical Control:** Generally, where labour and/or machinery costs are high and the work needs to be undertaken quickly, herbicides are used for weed control. Application costs can also be high, as it can also be labour intensive

and require specialised equipment. The inappropriate *use* of herbicides can damage indigenous plant communities and contaminate the environment.

The method employed must not be more damaging than the weed to be controlled. A wide range of herbicides play a major role in weed management. While the application of herbicides must be consistent with their label recommendations, these will not cover many existing weeds. Research and field trials are required to ascertain appropriate control measures for these species.

It is beyond the scope of this document to present detailed information on the control of particular pest species and readers are referred to the appropriate national texts.

7.4.3 Vegetation establishment techniques

As stated previously, the restoration of a wetland will involve mitigating degrading processes and agents. It will also be constrained by the prevailing environmental conditions, particularly the water regime. Once the prevailing environmental conditions have been determined, and these may or may not be the desired or natural conditions but those imposed by changes to the site, a strategy for vegetation re-establishment can be determined.

The 'wait and see' approach allows natural processes to operate and is least interventionist. The success of this approach does depend on the presence of propagules and/or the capacity of the existing vegetation to recover and colonise disturbed sites within the wetland. While vegetation re-establishment may be slower by such means and failures can result, these are often offset by the relative cost efficiencies of this method.

Where structurally or floristically significant species are known to have been lost from the site, the project manager may decide to undertake a replanting program. Where active revegetation is required, the project manager will need to decide what species are required, how plants of these species are to be obtained, where and how these plants are to be established, and what post-planting follow-up is required. There are a number of techniques from which to choose and the technique employed will depend on the objectives of the project, the site and time constraints, and the available dollars.

Propagation and establishment techniques

Wetland plants can be established by direct seeding, transplanting of divided or whole plants, establishment from cuttings and nursery propagation. Appendix 7a lists species and genera of Victorian wetland plants for which the propagation methods are known.

- **Direct-seeding**
  Direct-seeding into shallow water or onto mud can be successful for those species for which quantities of seed can be obtained. Success with direct seeding is highly variable, and depends on a number of natural factors over which the project manager will have no control. It would be expected that seeds and seedlings would be more susceptible to loss by predation and grazing and from the effects of dehydration, flooding, wave action and

salinity (Brooke *et al.* 1988). Despite this a number of species are reported to be readily established by this method. Jeffery (1988) and Ecological Horticulture (1989) list the following as species which can be established successfully from seed: *Alisma plantago-aquatica, Amphibromus gracilis, Amphibromus nervosus, Glyceria australis, Ottelia ovalifolia, Poa labillardieri, Rumex* spp., *Triglochin procera, Villarsia exaltata, Melaleuca* sp. *and Typha* spp. The performance of the *Typha* spp. from direct seeding at La Trobe University was poor when compared to its rapid vegetative spread (Jeffery 1988). Mangroves are reported by Buchanan (1989) to be readily established by direct seeding.

Despite its ability to colonise and spread on sites by vegetative means, *Phragmites australis* is not known to have been established by direct seeding in Victoria. Sainty and Jacobs (1981) suggest that the germination of this species occurs in only a narrow range of conditions.

- **Transplanting of parts or whole plants**

  Removing portions or entire clumps of rhizomatous species for transplanting is an established and successful technique. Transplanting wetland vegetation has been a common practice in some parts of the world for many years. Brooke *et al.* (1988) report in their review of tidal marsh restoration techniques that *Spartina townsendii* was transplanted in Europe as early as the 1920s and '30s, and *Spartina anglica* and *alternifolia* in China in the 1960s and 1970s. The US Army Corps of Engineers has been involved in over 100 experimental and applied tidal marsh planting projects on continental USA since the 1960s. Brooke *et al.* (1988) reported that transplanting tidal marsh vegetation is successful over a wider range of conditions than direct seeding. It was also reported that closer-spaced plantings have some advantages in establishing vegetation on marginal or particularly exposed sites.

  Poor establishment performance of *Phragmites australis* has been observed following transplanting by methods and under conditions where other species have been established successfully.

  Some species will also establish from cuttings planted directly into mud or shallow water, eg *Centipedia sp., Cotula* sp., *Crassula* sp., *Lobelia* sp., *Myriophyllum* sp. and *Polygonum* spp. (Ecological Horticulture 1989).

- **Nursery propagation**

  Material can be propagated from seed or cuttings under glasshouse conditions. This technique may have some advantages in some situations. Brooke *et al.* (1985) found that glasshouse grown plants of *Spartina* spp. established as well if not better than transplants. It was suggested from this work that the vermiculite and/or peat component of the propagating mix may provide some advantages to plants planted out onto low moisture sites (ie aid survival over the dry following initial planting, see planting time, below). Buchanan (1989) reports that mangrove transplants did not grow as well as naturally sown seed or nursery grown stock due to transplanting shock. Peat pots can be used to grow on seedlings so that stock can planted directly with minimum effort or dropped into water. Because seed or cuttings must be collected and grown on, at least one year of planning and preparation is required where this technique is used.

> Nurseries specialising in indigenous natives, propagate and may handle wetland species from time to time. While there may be time advantages in obtaining ready grown nursery stock, there are a number of disadvantages, and importantly stock are unlikely to be of local genic provenance and cost will be high. Commercial nurseries will grow on stock if provided with seed, thus ensuring local material is used and potentially lowering costs.

Re-established vegetation can be used as a source of material for transplanting in the same or other revegetation projects.

Where there is a requirement for rapid establishment, such as where landscape or aesthetic considerations are important, or on harsh or low nutrient sites, fertilisers can be used to facilitate plant establishment. Both conventional and slow release (eg Osmocote) fertilisers were used successfully to accelerate the growth and establishment of *Spartina* spp. on both low and average nutrient sites (Brooke *et al.* 1988). Buchanan (1989) reports that mangroves were grown most successfully in a propagating mix with a high fertiliser component.

Fertilisers have not been used in wetland revegetation works in Victoria (author's observation). Accelerated growth of *Schoenoplectus validus* has been observed where it has been planted in high nutrient situations (author's observation).

Planting time

The timing of the collection of material for propagation is very important. The majority of practitioners agree that planting is best carried out in spring and early summer as the natural establishment time for wetland species is when water levels are low and temperatures are high (Brown and Fricker 1985, Ecological Horticulture 1989). Gilespe (pers. comm.) had a high rate of establishment of transplants with an October planting followed by artificially high summer water levels. Planting should, however, be varied to suit and be influenced by local conditions, particularly the length of the growing season and degree of summer drying of the site. Muir[10] (pers. comm.) reported successful establishment of *Triglochin striata*, *Typha* spp. and *Juncus* spp. with late autumn—winter plantings at a coastal site.

Vegetative material can be collected in late winter and spring before extensive growth begins for spring planting. Material has been collected in autumn and stored in moist sand over winter.

It should be stressed that the re-establishment of wetland vegetation will not occur in one growing season, but will progress and develop over a number of seasons.

Species selection

The aim of revegetation should be to create a vegetation assemblage (community) that reflects the previous or desired natural vegetation pattern. Where this is unknown for the site to be restored, it may be modelled on wetlands of a similar physical type (on features including geomorphology and water quality) within the catchment. Other wetlands can provide a guide to structural and floristic composition, species distribution patterns, and as potential sites for sources of

---

[10] A. Muir, Flora & Fauna Branch, NRE

propagules. When choosing species that are potentially invasive, eg Cumbungi *(Typha* spp.), Common Reed (*Phragmites australis),* only introduce them to areas where they are known to have occurred or where there are natural barriers to their spread such as deep water areas. While species and structural diversity should be maximised, they should reflect previous vegetation patterns.

Position

Planting should attempt to reflect the distribution of species across the water depth gradient. Plants introduced to the site would, however, be expected to find their own niche to some extent because of the large number of variables that determine or influence the occupation of a site by a species.

Three generalised vegetation zones for planting freshwater wetlands have been recognised (Ecological Horticulture 1989).

These are :

1. the more or less permanently wet or damp margins with seasonal inundation to 10 cm deep; species include: *Amphibromus* spp., *Carex* spp., *Cotula* spp., *Eleocharis acuta, Juncus spp., Isolepis* spp., *Baumea* spp., *Gahnia* spp., *Polygon=* spp., *Ranunculus* spp.
2. areas subject to seasonal inundation to 60 cm deep; species include: *Alisma plantago aquatica, Amphibromus* spp., *Crassula* spp., *Carex* spp., *Baumea* spp., *Eleocharis* spp., *Myriophyllum* spp., *Ottelia ovalifolia, Phragmites australis, Potamogeton* spp., *Ranunculus* spp., *Triglochin procera, Villarsia reniformis, Typha* spp.
3. permanent or near permanent water to 2 metres fluctuating by about 0.5 metres; species include: *Eleocharis sphacelata, Ottelia ovalifolia, Phragmites australis, Potamogeton* spp., *Typha* spp., *Vallisnera* spp.

Species distribution is, as previously stated, best determined by observing the vegetation patterns of the wetland to be restored or other similar wetlands within the catchment.

Exposed sites may need some protection to aid establishment. A 10 cm polythene pipe has been used successfully on a small wetland to reduce wave action during the establishment of aquatic herbs.

Artificial establishment of wetland vegetation

When establishing indigenous wetland vegetation by natural means and processes is not appropriate or practical, establishment by planting out nursery grown stock, transplanting rootstocks, rhizomes, tubers, corms etc from one site to another can be carried out. The following factors should, however, be taken into consideration:

- Any removal of vegetative material from a wetland site should not adversely affect the donor site or compromise its ability to carry out its natural functions.
- Any material removed from a site should be healthy with no sign of disease or parasite infestation.

- Plants to be transplanted (translocated) to be collected in late winter to early spring before extensive growth begins:
  - cut rhizomes in lengths containing 2-3 nodes per rhizome;
  - reduce vegetative growth;
  - plant out immediately; where this is not possible, store in a cool moist medium (sand/sphagnum);
  - plant out under shallow water conditions in late winter to early spring—depth will be determined by the requirements of the species;
  - space plants to allow for lateral growth; this will depend on the rate of establishment, the aims of the project, the cost of planting and the availability of planting material; generally 0.3-1.5 metres is suggested. The higher the density of planting the sooner cover will be achieved.
  - NPK fertiliser tablets may be used with each planting.
- Nursery grown stock to be planted-out in early spring.

7.4.4 Water management as an aid to vegetation establishment in wetlands

It is now well documented that wetland productivity and wetland vegetation establishment are closely linked with periodic wetting and drying (Hertzman 1969, Meeks 1969, Neckles *et al.* 1990, Total Environment Centre 1989, Welling *et al.* 1988). The relationship between fluctuating water levels and vegetation diversity is now also recognised (Pederson and van der Valk). Neckles *et al.* (1990) report that seasonal wetlands support a higher densities of invertebrates than otherwise similar semi-permanent wetlands. Such increases in abundance are related not so much to environmental quality, rather to the environmental cues provided by rising and falling water levels.

The planned manipulation of water levels has long been used to manage wetland habitats in North America (Welling *et al.* 1988). Managed drawdowns typically last between one and two years. Managed drawdowns of two years or more were reported to have some detrimental side effects. A study by Welling *et al.* (1988) found that emergent species which established during the first year following drawdown, declined if drawdown extended into a second year. Mud flat annuals were promoted, however, when drawdown extended into a second year. With extended drawdown there is a trend toward the establishment of dryland species, and woody species at lower than normal elevations (Harris and Marshall 1963). The North American experience indicates that properly managed drawdowns of one year duration are successful in establishing stands of desirable emergent vegetation. Nothing is known of similar work in Victoria or for similar wetland types in Australia.

Harris and Marshall (1963) found during drawdown trials that desirable emergents persisted only for the first year following re-flooding, and that other emergents including *Typha latifolia* and T. *angustifolia* and *Carex* spp. persisted. The study concluded that drawdowns would be required every seven to eight years to maintain species and structural diversity.

Apart from producing conditions suitable for germination, drawdowns expose the substrate and promote the decomposition of organic material and this speeds the release of nitrogen and other nutrients in a form available for uptake by plants.

The manipulation of water in wetlands should aim to reproduce the natural wetting and drying patterns of the wetland type being restored. The magnitude and frequency of the natural water regime may be determined by examining other similar wetlands in the region (see 4.2.1 above).

In practice there would seem very few opportunities to artificially manipulate the water levels of natural wetlands in Victoria (Gipplen pers. comm.). The management of drawdowns and subsequent re-flooding requires drainage channels and water control structures that allow water to be drawn off gradually. The controlled filling of a wetland would be even more difficult given the need for a ready supply of water of the right quality.

The most appropriate aim of water management for wetlands is to re-instate as close a natural system as is possible, that is allow the natural wetting and drying patterns to shape and influence wetland vegetation.

In summary; when restoring wetland vegetation by maintaining or restoring natural water regimes a number of factors should be taken into consideration:

- The natural water regime of any wetland to be restored should be determined before any restoration works take place.
- Where the opportunity exists to manipulate water levels in a wetland to be restored, this should be done to mimic natural conditions.
- In general, drawdowns should:
  - aim to simulate the natural wetting and drying patterns of the wetland concerned;
  - be timed to occur over the period November through to January;
  - be a slow process with a gradual drop in water levels over the drawdown period.
- Once drawdowns are completed, drying should last for no more than 12 months, with reflooding occurring in the second winter period after drawdown.
- The frequency of drawdown should reflect natural wetting and drying patterns.
- All drawdowns should be monitored.

---

[11] C. Gipple, Department of Hydrology, Melbourne University

7.5 REFERENCES AND BIBLIOGRAPHY

Arthington A.H. and Mitchell D.S. 1986. Aquatic invading species. In : Groves R.H. and Burdon J.J. *Ecology of biological invasions*. Australian Academy of Science, Canberra.

Barber G.J. 1990. Practical aspects of aquatic plant establishment : Experiences at Brunswick and Bundoora. In: La Trobe University, *Wetlands, Their Ecology, Function, Restoration and Management*. Proceedings of the Applied Ecology and Conservation Seminar Series.

Beare P.A. and Zedler J.B. 1987. Cattail invasion and persistence in a coastal marsh: The role of salinity. *Estuaries* 10 (2):165-170.

Bibrowska H.B. and Robinson D.P. 1989. *An Assessment of the Ecological State of a Wetland Receiving Treated Sewage*. Environment Protection Authority, SRS 88/017, Melbourne.

Bjork S. 1974. The restoration of degraded wetlands. In : Smart M. (ed.). *International Conference on the Conservation of Wetlands and Waterfowl*. IWWRB Slimbridge Great Britain.

Boutin C. 1987. Domestic waste water treatment in tanks planted with rooted macrophytes. *Water Science Technology* 19(10):29-40.

Bowmer K.H. 1981. Nutrient enrichment ; Eutrophication; cause of problem plant growth, possibilities for regulation. In : Sainty G.R. and Jacobs S.W.L. *Plants of New South Wales*. Water Resources Commission of NSW, Sydney.

Briggs S.V. 1981 Freshwater wetlands, in Groves R. H. *Australian Vegetation*. Cambridge University Press, Melbourne.

Briggs S.V. 1988. Guidelines for management of inland wetlands in southern New South Wales. *Wetlands* (Australia) 8(1):1-2.

Broome S.W., Seneca E.D. and Woodhouse W.W. 1988. Tidal salt marsh restoration. *Aquatic Botany* 32:1-22.

Brown V., Fricker P. 1985. *Revegetation of Urban Creeks in the Yarra Catchment : Guidelines for the Establishment of Aquatic and Marginal Vegetation*. Melbourne Board Of Works.

Buchanan R.A. 1989. *Bush Regeneration; Recovering Australian Landscapes*. TAFE Student Learning, TAFE NSW.

Centre for Stream Ecology 1989. *Biological Effects of Saline Discharges to Streams and Wetlands*. Chisholm Institute of Technology, Caulfield.

Coats R., Swanson M. and Williams P. 1989. Hydrologic analysis for coastal wetland restoration, *Environmental Management* 13(6) November/ December.

Commonwealth of Australia 1977. *Aquatic Weeds in Australian Inland Waters*. Department of Environment Housing and Community.

Cunningham G.M., Multham W.E., Milthorpe P.L. and Leigh J.H. 1981. *Plants of Western New South Wales*. Soil Conservation Service of NSW, Sydney.

Dandenong Valley and Westernport Authority 1989. Pusilla flats (Tirhatuan wetlands): Ecology, Development and Management Strategy. *DVWA Technical report no* 33, Dandenong.

DCEWA 1980. *Guidelines for the Conservation and Management of Wetlands in Western Australia*. Bulletin No. 79, Department of Conservation and Environment, Western Australia.

DeLaune R.D., Smith C.J., Patrick W.H. Fleeger J.W. and Tolley M.D. 1984. Effect of oil on salt marsh biota: methods for restoration. Environmental Pollution 36(3):207-227.

Department of Primary Industry Queensland 1988. Weed Control in Small Farm Dams. Queensland Agriculture Journal 114(5).

Department of Water Resources 1989. Guidelines for Incorporation of Environmental Water Requirements in Planning New Water Projects. Rural Affairs, Conservation and Environment Committee of Cabinet, Victoria.

Dowling R. 1985. Report on Mangrove Restoration Trials Undertaken by Botany Branch Department of Primary Industries, Queensland.

Duxbury K. 1990. Wetlands at Malvern. In: La Trobe University. Wetlands, Their Ecology, Function, Restoration and Management. Proceedings of the Applied Ecology and Conservation Seminar Series.

Ecological Horticulture 1989. Vegetation Design and Establishment Techniques for the Lilydale Lake Project, Lilydale Victoria, a report prepared for the Melbourne Board of Works.

Faber P. 1983. Marsh restoration with natural revegetation: a case study in San Francisco bay. Coastal Zone pp. 729-734.

Finlayson M.C., Roberts J., Chick A.J. and Sale P.J.M. 1983. The biology of Australian weeds, Typha spp. Journal of the Australian Institute of Agricultural Science pp. 3-10.

Fisheries Division 1983. A Guide to Transplanting Mangroves. Department of Agriculture NSW

Fonseca M.S., Judson Kenworthy W. and Thayer G.W. 1988. Restoration and management of seagrass systems: a review. In : Hook D.D. et al.. Management, Use and Value of Wetlands. Croom Helm, Sydney.

Frankland B., Bartley M.R. and Spence D.H.N. 1987. Germination Under Water. In: Crawford R.M.M. Plant Life In Aquatic And Amphibious Habitats. British Ecological Society Publication number 5, Blackwell Scientific Publications.

Frood, D., (in prep). The Vegetation of Victorian Wetlands. A report to the Wetlands Unit, Department of Conservation and Environment, East Melbourne.

Frood D. and Calder M. 1987. Nature Conservation in Victoria Study Reports, vol. 1 and 2, VNPA Press, Melbourne.

Gillison A.N. and Anderson D.J. 1981. Vegetation Classification in Australia. ANU press, Canberra.

Groves R.H. (ed.) 1981. Australian Vegetation. Cambridge University Press, Melbourne.

Gryseels M. 1989. Nature management experiments in a derelict reed marsh: 1. effects of winter cutting. Biological Conservation 171-193.

Hamilton L.S. and Snedaker S.C. 1984. Handbook for Mangrove Area Management. Commission of Ecology, IUCN, Switzerland.

Harper M.J. 1990. Water bird dynamics at Bool Lagoon, South Australia, 1983-87. Australian Wildlife Research 17:113-122.

Harris S.W. and Marshall W.H. 1963. Ecology of water level manipulation on a northern marsh. Ecology 44(2):331-343.

Hedditch M. and Stubbings P. (undated). Keeping on Top of Cumbungi. NSW Department of Agriculture, Griffith NSW.

Hertzman T. 1986. Restoration of Lake Hornborga-results from development of methods for wetland management. Proceedings of 7th Symposium on Aquatic Weeds.

Hey D.L. 1987. Des Plaines river wetlands demonstration project : developing and implementing goals and objectives. In : Zelazny J. and.Feierabend J.S. Wetlands. Increasing Our Wetland Resources, Proceedings of the National Wildlife Federation Corporate Conservation Council Conference, Mayflower Hotel Washington DC.

Hill D. and Edquist N. (undated). *Wildlife* and Farm Dams. Graduate school of environmental science, Monash university, Clayton, Victoria.

Hoffman R.D. 1987. Ducks Unlimited's United States construction program for enhancing waterfowl production. In : Zelasny J. and Feierabend J.S. Wetlands. Increasing Our Wetland Resources, Proceedings of the National Wildlife Federation Corporate Conservation Council Conference, Mayflower Hotel Washington DC.

Jeffery M. 1988. Report on the Indigenous and Aquatic and Semi-aquatic Plant Species Located Within the Yarra Valley Metropolitan Park, and Techniques for Their Establishment in Future Wetland Areas. Melbourne Board of Works.

Kadlec J.A. and Smith L.M. 1984. Marsh establishment on newly flooded salt flats. Wildlife Society Bulletin 12(4):388-394.

Kadlec R.H. 1987. Monitoring wetland responses. In: Zelasny J. and Feierabend J.S. Wetlands. Increasing our Wetland Resources, Proceedings of the National Wildlife Federation Corporate Conservation Council Conference, Mayflower Hotel Washington D. C.

Kiddle G. 1987. River Red Gum (Eucalyptus camaldulensis) Regeneration Along the River Murray in South Australia. Conservation Projects Branch, Conservation Programmes Division, Department of Environment and Planning, Adelaide.

Larson J. S. 1987. Wetland creation and restoration : an outline of scientific perspective. In : Zelasny J. and Feierabend J.S. Wetlands. Increasing our Wetland Resources, Proceedings of the National Wildlife Federation Corporate Conservation Council Conference, Mayflower Hotel Washington D. C.

Leck M.A. and Graveline K.J. 1979. The seed bank of a freshwater tidal marsh. American Journal of Botany 66:1006-1015.

Leck M.A., Graveline K.J. 1987. Seed bank of a freshwater tidal marsh: turnover and relationship to change. American Journal of Botany 74:360-370.

Lou Gay B. and Tanacredi J.T. (?) Shoreline stabilisation through marsh restoration. Parks pp. 19-20.

Love L.D. 1981. Mangrove swamps and salt marshes. In : Groves R.H. Australian Vegetation. Cambridge University Press, Melbourne.

Madsen C. 1986. Wetland restoration: a pilot project. Journal of Soil and Water Conservation, May—June , pp. 159 — 160.

Mitchell D.S. and Roberts J. 1984. Wetland management philosophies and principles. Wetlands, National Parks and Wildlife Service NSW, Sydney.

Mallick A.U. and Wein R.W. 1986. Response of Typha marsh community to draining, flooding and seasonal burning. Canada Journal of Botany 64:2136-2143.

Meeks R.L. 1966. The effect of drawdown date on wetland plant succession. Journal of Wildlife Management 33(4):817-821.

Metz E.D. 1987. Guidelines for planning and designing a major wetland restoration project : Ballona wetland case study. In Zelasny J. and Feierabend J.S. *Wetlands. Increasing our wetland resources, Proceedings of the National Wildlife Federation Corporate Conservation Council Conference,* Mayflower Hotel Washington D. C.

Murray—Darling Freshwater Research Centre 1988. Report on investigations into the role of vegetation in protecting river banks from erosion. *M.F.R.C. Annual Report* 1988-89.

Neckles H.A., Murkin H.R. and Cooper J.A. 1990. Influences of seasonal flooding on macroinvertebrate abundance in wetland habitats. *Freshwater Biology* 23:311-322.

Nuttall R.J. 1985. Aquatic weed control in lake Wendouree Ballarat. *Memo* 63:42-49.

Nuttall R.J. and Archibald R.K. (undated) *Biocontrol of cumbungi* (Typha spp.) *in drainage and irrigation channels in Victoria.* Dandenong Valley and Westernport Authority (for The Australian Institution of Engineers), Dandenong.

Odum W.E. 1987. Predicting ecosystem development following creation and restoration of wetlands. In Zelasny J. and Feierabend J.S. *Wetlands. Increasing our wetland resources, Proceedings of the National Wildlife Federation Corporate Conservation Council Conference,* Mayflower Hotel Washington D. C.

Pederson R.L. and van der Valk A.G. 1984. Vegetation change and seed banks in marshes: ecological and management implications. *Transcripts of the North American Wildlife and Natural Resource Conference* number 49.

Race M.S. 1983. An assessment of salt marsh restoration and implications for coastal zone management. *Coastal Zone* pp. 1473-1487.

Race M.S. 1986. Wetlands restoration and mitigation policies: reply, *Environmental Management.* 10(5):571-572.

Race M.S. 1985. Critique of present wetland mitigation policies in the United state based on an analysis of past restoration projects in San Francisco bay. *Environmental Management* 9(1):71–81.

Reddy K.R. and De Busk T.A. 1987. State-of-the-art utilisation of aquatic plants in water pollution control. *Water Science Technology* 19(10):61-79.

Robinson D.P. 1988. *Environmental effects of Dutson Downs wastewater on Lake Coleman.* Environment Protection Authority, SRS 88/006, Melbourne.

Romanowski N. (undated) Creating or restoring a wetlands area. In : Society for Growing Australian native Plants Maroondah Group, Inc. *Flora of Melbourne, A Guide to the Indigenous Plants of the Greater Melbourne Area.*

Ross J.H. 1990. *A census of the vascular plants of Victoria.* National Herbarium of Victoria, Department of Conservation and Environment, Melbourne.

Royle R. 1987. Eutrophication: the wetland's hidden cost. *The Australian Environmental Management Review Newsletter,* vol 2, pp. 25.

Sainty G.R. and Jacobs S.W. 1981. *Plants of New South Wales.* Water Resources Commission of NSW, Sydney.

Sale P.J.M. and Wetzel R.G. 1983. Growth and metabolism of *Typha* spp. in relation to cutting treatments. *Aquatic Botany* 15:321-334.

Sharp V. 1990. Built wetlands: wetland vegetation. *Newsletter,* Victorian Wetlands Trust, East Melbourne.

Smith L.M. and Kadlec J.A. 1983. Seed banks and their role during drawdown of a North American marsh. *Journal of Applied Ecology* 20:673-684.

Smith L.M. and Kadlec J.A. 1985. The effects of disturbance on marsh seed banks. *Canadian Journal of Botany* 63:2133-2137.

Snyder C.D. and Aharrah E.C. 1986. The Typha community: a positive influence on mine drainage and mine restoration. In : Brooks R.P., Samuel D.E. and Hill J.B., *Wetlands and Water Management on Mined Lands,* Proceedings of a Conference, October 1985, Pennsylvania State University.

Soernsen J. and Gates S. 1983. New directions in restoration of coastal wetlands, *Coastal Zone 1983,* pp. 1427 — 1443.

South Australian River Murray Wetlands Working Party 1989. *Enhancing Wetlands.*

Spetch, R.L. 1981. Responses to fire in heathlands and related shrublands. In : Gill A.M., Groves R.H. and Noble I.R., *Fire and the Australian Biota.* Australian Academy of Science, Canberra.

State Pollution Control Commission NSW (undated) *Pollution Control Manual for Urban Stormwater.* Government of NSW, Sydney.

Thompson D.J. and Shay J.M. 1985. The effects of fire on *Phragmites australis* in the delta marshes of Manitoba Canada. *Canada Journal of Botany* 63:1864-1869.

Total Environment Centre 198?. Macquarie Marshes-Wetlands Management Requirements. Total Environment Centre, Sydney.

van der Valk A.G. 1981. Succession in wetlands: a Gleasonian approach. *Ecology* 62(3):688-696.

Warburton D.B., Klimstra W.B. and Nawrot J.R. 1986. Aquatic macrophyte propagation and planting practices for wetland establishment. In : Brooks R.P., Samuel D.E. and Hill J.B., *Wetlands and Water Management on Mined Lands.* Proceedings of a Conference, October 1985, Pennsylvania State University.

Welling C.H., Pederson R. and van der Valk A.G. 1988. Temporal patterns in recruitment from the seed bank during drawdowns in a prairie wetland. *Journal of Applied Ecology* 25:999-1007.

Whitman W. R. 1974. Artificial wetlands for waterfowl. In : Smart M. (ed.). *International Conference on the Conservation of Wetlands and Waterfowl.* IWWRB Slimbridge England.

Wienhold C.E. and van der Valk A.G. 1989. The impacts of duration of drainage on the seed banks of northern prairie wetlands. *Canadian Journal of Botany* 67(6):1878-1884.

Williams P.B. and Harvey H.T. 1983. Salt marsh restoration design. *Coastal Zone* 1983, pp. 1444-1455.

Williams W.D., 1985. Biotic adaptations in temporary lentic waters, with special reference to those in arid and semi-arid regions. *Hydrobiologia* 125:85-110.

Zedler J.B. 1988. Why It's So Difficult To Replace Lost Wetland Functions. In : Zelazny J. and Feierabend J. S. *Wetlands. Increasing our wetland resources, Proceedings of the National Wildlife Federation Corporate Conservation Council Conference,* Mayflower Hotel Washington D. C.

Zelazny J. and Feierabend J.S. 1987. *Wetlands. Increasing our wetland resources, Proceedings of the National Wildlife Federation Corporate Conservation Council Conference,* Mayflower Hotel Washington D. C.

7.6 APPENDICES

Appendix 7a Propagation and establishment techniques for some genera and species of Victorian wetland plants

Propagation and establishment techniques

The following techniques and procedures are recommended for revegetation projects in Victorian wetlands.

Transplanting

Where a source of material is available and the technique suits the target species, transplanting plant material from one wetland site to another is a successful revegetation technique. Rushes, sedges and grasses and many wetland dicotyledons can be successfully transplanted.

The following procedure is recommended when transplanting wetland species:

- plants to be collected with roots and/or rhizomes intact. Large soil corers can be used to take plugs from within clumps of herbaceous species (augers are not suitable because the inward pointing blades damages plant roots);
- collect plants to be transplanted in late winter to early spring before extensive growth begins;
- rhizomes may be cut into lengths containing 3-5 nodes per rhizome;
- when dividing plants, keep them moist and sheltered from hot sun or drying wind; observe proper hygiene to minimise fungal infections;
- reduce vegetative growth by one-third;
- transplants should be planted out (in late winter to early spring) as soon as practical after they has been collected. Where this is not possible, store in a cool, moist medium (sand/sphagnum) until planting.

Vegetative material selected for transplanting should be disease-free. Transplanting of plant material from sites infested with pest plants should also be avoided. Table 1 (section 7.4.2.4.) lists introduced plant species that are naturalised in Victoria and that can be problematic in wetlands.

The establishment of *Phragmites australis* has been problematic on a range of sites in southern Victoria. Where this species is to be established, planting of transplants at or above the high water mark should be trialed.

Nursery propagation

Where nursery-grown stock is required, the following procedures should be followed:

- Aquatic and amphibious species can be propagated from seed in nurseries by simulating field conditions of:

  low water levels; maintain 3-5 cm of water over a suitably sandy or silty substrate in a water tight container. Sow seed, which in some species may float for a time, onto the water surface.

ii an exposed but saturated substrate; sow seed onto the surface of a suitable sandy or silty medium. Stands pots in water to just below the surface of the growing medium.

- Peat or paper-based propagation pots may have some advantages for propagation, growing-on or planting-out by minimising handling and aiding summer moisture retention in the field.

Some wetland species can also be propagated in the nursery from cuttings; species that can be propagated by this method are listed below. Planting-out of nursery grown stock should occur in late winter to early spring.

Direct seeding

Where sufficient quantities of seed are available, direct seeding is an appropriate re-establishment technique for some wetland species, and those species that can be successfully established using this method are listed below. The direct seeding of most herbaceous wetland species will usually be secondary to the use of transplants or nursery stock. Direct seeding will have the greatest application for the establishment of woody species, eg for species of Melaleuca, Leptospermum, Callistemon and Eucalyptus. Direct seeding should take place under conditions of saturated soil or in shallow warm water (after the autumn break or in late spring to early summer).

Some wetland species and their propagation

Species **or Genera**	**Common names**	**Techniques**		
		(i)	**(ii)**	**(iii)**
Alisma plantago-aquatica	Water Plantain	+	+	S
Altemathera denticulata	Lesser Joyweed		+	S,C
Amphibromus nervosus	Veined Swamp Wallaby Grass	+	+	D,S
Angianthus preissianus	Common Cup Flower			S
Avicennia marina	White Mangrove			S*
Azolla spp.	Azolla		+	D
Baumea spp.	Twig-rushes		+	D,S
Bolboschoenus spp.	Club-rushes		+	D,S
Boronia parviflora	Swamp Boronia			C
Brachyscome cardiocarpa	Swamp Daisy		+	S,C
Callistemon spp.	Bottlebrush		+	S,C
Callitriche spp.	Starwort		+	D
Calotis spp.	Burr Daisy			S,C
Calotis scapigera	Tufted Burr Daisy		+	C,D
Calystegia sepium	Greater Bindweed		+	C,S
Cardamine spp.	Bitter Cress		+	D,C
Carex spp.	Sedge		+	D,S
Centella cordifolia	Centella		+	D,C
Centipeda cunninghamii	Common Sneezeweed		+	C,S
Ceratophyllum demersum	Common Homwort		+	
Chenopodium spp.	Goosefoot			C,S
Craspedia glauca	Common Billy Buttons			D,S
Crassula helmsii	Swamp Crassula		+	D,C
Cyperus spp.	Sedges		+	D,S
Damasonium minus	Star-fruit			D
Desmodium gunnii	Slender Trick-foil			C,Ss
Disphyma crassifolium	Rounded Noon-flower		+	C,S
Eclipta platyglossa	*Yellow* Twin-heads			C,S
Elatine gratioloides	Waterwort		+	C,S

Species or Genera	**Common names**	**Techniques**		
		(I)	**(ii)**	**(iii)**
Eleocharis spp.	Spike-rushes		+	D,S
Epilobium hirtigerum	Hairy Willow-herb		+	C,S
Era grostis infecunda	Cane Grass		+	D,S
Erygium vesiculosum	Pricklefoot			Cr
Eucalyptus spp.	Eucalypts		+	S
Euphorbia drummondii	Flat Spurge			S
Frankenia pauciflora	Southern Sea Heath		+	C,S
Gahnia siberiana	Sawsedge		+	S
Glossostigma elatinoides	Small Mudmat		+	C,Sf
Glyceria australis	Australian Sweet-grass		+	D,S
Gnaphalium indutum	Tiny Cudweed			C,S
Goodenia spp.	Goodenia		+	C
Gratiola peruviana	Austral Brooklime		+	C
Halosarcia spp.	Glassworts			S
Helichrysum rutidolepis	Pale Everlasting			C,S
Hemarthria uncinata	*Mat* Grass		+	D,S
Hemichroa pen tandra	Trailing Joint Weed			C
Hydrocotyle sibthorpioides	Shining Pennywort		+	C,D
Isachne globosa	Swamp Millet		+	D,S
Isolepis spp..	Club-rushes		+	D
Juncus spp.	Rushes		+	D,Sf
Lawerencia spicata	Salt Lawerencia			S
Lemna disperma	Duckweed			D
Lepidium aschersonii	Swamp Peppercress			S
Lepilaena spp.	Water-mat			D
Leptinella reptans	Creeping Cotula		+	D
Leptospermum spp.	Tea-trees			C,S
Levenhookia dubia	Hairy Stylewort			S
Lilaeopsis polyantha	Australian Lilaeopsis		+	D,S
Limonium australe	Native Sea Lavender			S
Linum marginale	Native Flax			S
Lobelia alata	Angled Lobelia		+	D,S
Lobelia pratioides	Poison Lobelia			S
Lycopus australis	Australian Gipsywort		+ D,S,C	
Lythrum hyssopifolia	Small or Lesser Loosestrife			C,S
Lythrum salicaria	Purple Loosestrife		+	C,S
Marselia drummondii	Nardoo		+	D
Melaleuca spp.	Paperbarks		+	S
Mentha spp..	Native Mints		+	C
Mimulus repens	Creeping Monkey-flower		+	D
Montia australasica	White Purslane		+	D
Muehlenbeckia florulenta	Twiggy Lignum			C
Myoporum parvifolium	Creeping Boobialla			C,S
Myriocephalus rhizocephalus	Woolly-heads			S
Myriophyllum spp.	Water Milfoil		+	C,D
Ottelia ovalifolia	Swamp Lily	+	+	S
Phragmites australis	Common Reed		+	D
Philydrum lanuginosum	Woolly Water Lily		+	D
Poa labillarderia	Tussock Grass	+	+	S
Persicaria spp.	Knotweed		+	C,S
Podelepis jaceoides	Showy Podelepis			S
Potamogeton crispus	Curly Pondweed		+	D

Species or Genera	**Common names**	**Techniques**		
		(I)	**(ii)**	**(iii)**
Potamogeton ochreatus	Blunt Pondweed		+	D
Potamogeton tricarinatus	Floating Pondweed		+	D
Pratia spp.	Pratia		+	D
Pseudognaphalium luteoalbum	Jursey Cudweed			S
Rhagodia candolleana	Seaberry Saltbush			C
Ranunculus spp.	Buttercup		+	D,S
Rumex spp.	Native Docks			D,S
Ruppia spp.	Sea Tassel		+ D,Sm	
Rutidosis leptorryhnchoides	Button Wrinkewort		+	D,S
Samolus repens	Creeping Brookweed		+	D,S
Sarcocomia spp.	Glassworts		+	C,D
Schenoplectus validus	River Club-rush		+	D,S
Sclerolaena muricata	Black Roly-poly			S
Seffiera radicans	Swamp Weed		+	
Senecio spp..	Fireweeds			S
Sueda australis	Austral Seablite			C
Triglochin procera	Water-ribbons	+	+	S
Triglochin striata	Streaked Arrow-grass			D,S
Typha spp.	Cumbungi	+	+	S,D
Vallisneria americana	Eel-grass		+	D,S
Villarsia spp.	Marsh-flowers		+	D,S
Zostera muelleri	Dwarf Grass-wrack		+	

Key **to Appendix** 7a
(I) Direct Seeding
(ii) Transplanting whole or divided plants
(iii) Nursery Propagation by:
S Seed * seed germinates on the parent plant; seeds can be grown under nursery conditions but seedlings need to be irrigated with brackish water.
f germinate from fresh seed
m plant ripe seed in saturated growth medium
s scarification of seed required to stimulate germination
C Cutting
r propagation from root cutting
D Divided Material

Source: Ecological Horticulture 1989, Gilespe pers. comm, Muir pers. comm., Society For Growing Australian Native Plants Maroondah Inc. 1991, DCE undated.

8 AQUACULTURE

8.1 INTRODUCTION

In December 1992, Victoria agreed to the general principles of the National Ecological Sustainable Development Strategy and has subsequently been an active participant in embracing the concept of ecologically sustainable development (ESD) as a basis for fisheries resource management (Gladwin 1992).

The Victorian Fisheries Strategic Plan 1994-1997 provides a vision for the future management of Victoria's fisheries resources which clearly supports the commercial development of the fishing industry within an ESD framework. One of the long-term objectives of this strategy is to 'encourage and facilitate the development of aquaculture', but ensuring that our aquatic ecosystems are managed so that they collectively provide the complete range of conservation, social and economic values for the community.

This chapter has been prepared, in support of this initiative, as an informative guide for agencies and authorities responsible for the wise use and conservation of Victoria's wetlands. Its particular aim is to outline the various planning and management considerations necessary in assessing the use of wetlands for aquaculture and other fisheries-related developments.

8.1.1 Definitions

For the purposes of this document, aquaculture is defined as the rearing of aquatic organisms under controlled or semi-controlled conditions.

It includes:

- the manipulation of the wetland environment to induce or enhance production of the cultured organisms; and
- the stocking of wetlands with brood stock or stock for on-growing.

Wetlands are often used for other fisheries such as harvesting 'wild' stocks of fish and invertebrates. Recreational and/or commercial fishing occurs in most wetlands. Some of these fisheries, particularly those in larger estuaries that are important commercially and recreationally, will not be discussed in this guide except where conflicts arise.

8.1.2 Scope of the chapter

This chapter provides information relevant to developing guidelines for the wise use of wetlands for aquaculture and other fisheries. It does not cover management procedures such as issuing permits.

8.1.3 Policies and regulations

The management of wetlands is controlled at the state and local level. **In** Victoria, two agencies are involved in approving or rejecting the use of wetlands for aquaculture and other fisheries. These agencies are the Department of Natural Resources and Environment (NRE) and the Department of Planning and Development (DPD). Each agency has individual responsibilities relating to wetlands, aquaculture and fisheries. Under these circumstances, there needs to be a co-ordinated approach to decision-making consistent with established policies.

For all Victorian waters, the State Environment Protection Policy S13 (1988) aims to attain and maintain levels of water quality that are sufficient to protect the specified beneficial uses of surface waters.

No development will be approved if it could reduce the quality of water required for uses such as:

- maintaining natural aquatic ecosystems and associated wildlife,
- water-based recreation,
- agricultural water supply,
- potable water supply,
- production of molluscs,
- use of edible fish and crustaceans, or
- industrial water use.

The Environment Protection Authority (EPA), a statutory body administered by NRE, refers to this policy when considering works applications, licence approvals and for enforcement purposes. The EPA places different criteria on discharges depending on the water use. These uses are called 'beneficial uses of water' and include water for drinking, recreation, cooling of power plants etc. The EPA issues a works approval to construct discharge facilities. When the works are completed, an inspection is made and a waste discharge licence may be issued.

Where aquaculture activities present hazards to navigation, the Port Authorities (Geelong, Melbourne, or Portland) have jurisdiction.

Where applicable, approval for development along coastal areas inside municipal boundaries, but outside Port Phillip Bay, must be sought from the local council who will refer it to the Coastal Management Co-ordinating Committee (which has NRE representation). In Port Phillip Bay, local municipal Councils have statutory responsibilities in assessing and approving aquaculture developments, with NRE acting as a referral authority. Applications for aquaculture developments outside local council jurisdiction require approval from NRE.

Government initiatives to standardised policy on the issue of planning permits for coastal developments, along the coastline and all embayments within municipal boundaries, is a function of the Coastal and Bay Management Council.

For inland waters, NRE is the primary managing agency and local councils act as referral bodies where planning permits are required for aquaculture. NRE is the lead agency for the management of fish culture. Within this department, the Fisheries Branch processes fish culture permits for operations on both private and public lands. The Fisheries Branch controls aquaculture under the Fisheries Act 1968, Part 5: Fish Culture and Part 6a: Fish Diseases. Sections 4 and 45 (research permits) have also been used to authorise fish culture activities.

The Fisheries (Amendment) Bill 1995 provides for a 21-year fish culture permit for aquaculture in waters on public land or for Crown waters on freehold land. Licensees operating in marine waters with fish culture permits do not have exclusive access rights to designated areas.

8.2 EXISTING AND POTENTIAL ACTIVITIES

Most commercial fisheries in wetlands occur in estuaries where wild stocks can be harvested (bream, whiting, flathead, snapper, pilchards, mussels, squid, bait worms etc.). Exceptions in freshwater wetlands include the commercial harvest of eels, yabbies, redfin, carp, baitfish and some native fish species. For the most part, the scope of these fisheries is small, particularly in freshwater environments. It is unlikely that there will be any significant further development in this area mainly because of reducing levels of stocks of some species and of limited entry into these fisheries. There is, however, potential for further development of aquaculture in wetlands; both for existing and new operations.

Existing operations within Victorian estuarine wetlands are tabulated below.

Abalone

Number of operations:	1
Locations.	clean water with marine salinities at Avalon
Types of operations:	intensive onshore
Area:	approximately 100 ha
Specific issues:	increased nutrients in effluent from on-shore operations (effluent treated and used on-site)
Specific environmental controls:	none

Mussels

Number of operations:	10
Locations:	deep water estuaries
Types of operations:	surface and subsurface long-lines
Area:	approximately 100 ha
Specific issues:	landscape degradation, nutrient stripping, water quality, conflicting uses
Specific environmental controls:	navigation, public health monitoring

Oysters, Flat

Number of operations:	none at present, future operations uncertain
Locations:	shallow bays for nursery and deeper water for grow-out
Types of operations:	post-nursery
Area:	unknown
Specific issues:	commercial utilisation of marine parks, turbidity caused by cleaning operations, availability of port facilities.
Specific environmental controls:	none

Oysters, Pacific

Number of operations:	1
Locations:	clean water with marine salinities at Avalon
Types of operations:	racks and bags in open ponds
Area:	approximately 100 ha
Specific issues:	increased nutrients in effluent from on-shore operations (effluent treated and used on-site)
Specific environmental controls:	no stocking in areas where feral populations could establish

Existing operations within freshwater wetlands include:

Eels

Number of operations:	6 licensees operating at 15 sites
Locations:	fresh and brackish waters south of the Great Divide in designated culture waters
Types of operations:	extensive; stocking of elvers and relocation of juvenile eels for on-growing
Area:	unknown
Specific issues:	translocation of diseases (eg Vibrio varieties), genetics, addition of a *new* predator to wetlands, wildlife by-catch in fyke nets, biomass removal (decreased production of ecosystem and decreased standing crop of eels), commercial exploitation of a reserved area, conflict with recreational fishers
Specific environmental controls:	no stocking in catchments outside of natural range, conditions of culture permit as set out in the Eel Management Plan (1995)

Yabbies
(all commercial farming takes place on private land)

Number of operations:	in excess of 130
Locations:	Victoria-wide
Types of operations:	intensive pond to extensive use of semi-natural waters and wild fishery
Area:	approximately 200 ha
Specific issues:	translocation of genetic stock and diseases, addition of nutrients, removal of biomass, alteration of hydrology, recreation versus commercial, importation of non-indigenous species (eg marron).
Specific environmental controls:	no stocking in far east of State

Trials, potential operations and requests include:

- extensive aquaculture of freshwater wetlands where species are not confined and habitats are manipulated to increase production—yabbies, Golden Perch, Silver Perch, bait fish, Goldfish, brine shrimp, mud-eyes, aquatic plants (micro-algae, duckweed, *Gracilaria);*
- confining and cage culture—several marine and freshwater species: snapper, salmonids, and eels;
- culture of barramundi in thermal groundwater resources;
- use of saline-affected ground or surface water to culture salt-tolerant fish species such as salmonids and silver perch;

- use of saline groundwater effluent (salinities up to and exceeding seawater concentrations) to culture marine species;
- culture of flounder species in lagoons at Avalon saltworks;
- fee for recreational use—fishing and hunting;
- further 'opening up' of wetlands not presently available for culture.

8.3 EFFECTS OF AQUACULTURE

Even though aquaculture is commonly viewed as a 'clean' industry (Weston 1991), it can have an impact on its surroundings, both living and non-living. These impacts are very much dependent on the sensitivity of the environment in which it operates and the scope of the development, whether it is conducted in-stream or off-stream, in estuarine waters or inland waters, is intensive or extensive etc. The following sections outline the potential effects of aquaculture, and their possible impacts on wetland values, to highlight the need for the development of flexible planning guidelines. Fortunately, many potential adverse effects of culture can be mitigated or eliminated by care in site selection and operation (Weston 1991).

8.3.1 Physical changes

Aquaculture can adversely affect the environment through physical disturbances, such as removing vegetation, constructing ponds, deepening shallow wetlands or by altering flow regimes with cages or stakes. In oyster and mussel farms, sedimentation occurs from excretory products and the trapping of suspended particles due to reduced water movement (Eng *et al.* 1989). In some cases, habitat may be disturbed by the action of fishing gear, such as beach seines. Manipulation of water levels can reduce habitat when water levels are lowered; or change natural regimes if water levels are held constant.

8.3.2 Input of nutrients

Aquaculture operations generate wastes that can have a significant effect on the surrounding physical, chemical and biological environment (Weston 1991). The main sources of waste are uneaten food, excreta, chemicals and, to a lesser extent, dead animals (Beveridge *et al.* 1991), feed dust particles (Purser 1993), scales and mucus (Phillips *et al.* 1985). However, the level of waste production and accumulation is very much dependent on the siting and methods employed in the aquaculture operation, and the species being cultured. For example, an oyster farm in a coastal or estuarine area is reliant on the natural productivity and high exchange rates of seawater for growth and water quality maintenance. An intensive, on-shore eel culture, on the other hand, operates with lower water exchange rates and uses nutrient additives for growth, requiring 'active' management of the accumulated food debris, metabolic wastes and other chemicals in the pond.

Uneaten food may be processed by microbes or the soluble parts dissolved into the water (Schroeder *et al.* 1991). In moving water, food pellets are suspended longer than in static water. During this suspension, the soluble fraction will dissolve into the water column and the pellet will fragment into many smaller particles that will be deposited elsewhere (Frid and Mercer 1989). Few attempts have been made to estimate directly the proportion of uneaten food, but work on pond and cage culture of salmonids suggest that this can be up to 30% (Warrer-Hansen 1982). Feed losses from cages are considerably greater than those from ponds (Beveridge *et al.*1991). The waste from food is a prime source of phosphorus, the element that is the limiting nutrient for the growth of most algae in freshwater (Phillips and Beveridge 1986; Weston 1991). Although there have been many instances of harmful algae causing mass mortality of caged fish, there is no evidence that these events were due to the release of waste compounds from the fish farms (GESAMP 1991). No major blooms have been recorded on Tasmanian salmon farms (Purser 1993). Even so, clearly a reduction in phosphorus in diets could help to reduce environmental impact (Phillips and Beveridge 1986). There may also be scope for controlling the leaching of phosphorus from faeces by formulating pellets which produce more water-stable faeces (Phillips, Clarke and Mowat 1993).

Waste from excreta comes from faeces, ammonia and urea production and from the elimination of gut bacteria. Faeces, in particular, can cause waste problems because of the large proportion of undigested food it can contain. Depending upon the species, about 27 to 41 g of undigested food is released as faeces per 100 g of food ingested (Beveridge *et al.* 1991).

Aquaculture operations frequently release wastes into nearby waterbodies. The nature of this effluent can vary enormously from site to site. Many variables influence effluent quality. These variables include species, size, method and intensity of culture, management practices and temperature. It is impossible to predict effluent characteristics with any accuracy (Beveridge *et al.* 1991). The most important factors to consider are the culture system and its management. Effluent waste concentrations can be reduced by prevention and treatment, with particular emphasis on solids removal. Although the prospects for treatment of effluent from cages or rafts seem poor (Beveridge *et al.* 1991), options for effluent treatment in on-shore culture sites are being constantly investigated. The initial use of settling ponds and the subsequent diversion of effluent to salt production parts or to dry lagoons for wetland enhancement is proving an effective measure at Avalon. Ford and Robertson (1995) have suggested the use of wetland vegetation, bivalves, seaweeds or bacteria as a means of stripping the nutrients from the effluent discharge, although some of these techniques require further study.

Summary

- Main sources of nutrients are uneaten food, excreta and chemicals.
- Proportion of uneaten food can be as high as 30%.
- Feed losses from cages are higher than from ponds.
- Feed losses from ponds (as distinct from races) are usually zero.
- Waste from food is a prime source of phosphorus which greatly influences production of algae in freshwater.
- The type of culture system and its management are the most important factors to consider in controlling nutrient input and output.
- The volume of fish held is also an important factor.

8.3.3 Use of chemicals

A wide range of chemicals are used in aquaculture: vaccines, hormones and water treatment compounds. Some chemicals come from the materials used by the industry, such as antifouling paints for combating biofouling of nets, encrusting facilities such as netcages and fish tanks (anon. 1992a; Schnick 1991). Many of these chemicals pose environmental risks if misused or if their dangers go unrecognised (Weston 1991). They can be released directly into the marine or freshwater environment while others may slowly leach out from the construction materials as with antifouling compounds.

The use of antibiotics is of special concern because they can potentially stimulate antibiotic resistance in the microbial community (Weston 1991; Aoki 1989). Samuelsen (1989) reported that fish take up only 20-30% of antibiotics in feeds, the remaining 70-80% end up in the environment. In finfish culture, the use of antibiotics has resulted in the appearance of resistant bacterial strains near culture sites (Bullock et al. 1974; Aoki, Jo and Egusa 1980; Austin 1985).

The use of chemo-therapeutic drugs in aquaculture have been know to also have toxic effects on wild living organisms or to produce quantitative and qualitative changes in the microbial flora (Jacobsen and Berglind 1988; Samuelsen 1989).

Summary

- Chemicals can be directly added to aquaculture waters as management controls or be introduced indirectly, as leachate from construction materials.
- Use of therapeutic chemicals can stimulate antibiotic resistance in the microbial flora and, in some cases, be toxic to living organisms.

8.3.4 The effects on indigenous biota

Deposition of food and faeces changes the composition and abundance of invertebrate populations, including a reduction of species richness and increased densities of opportunistic species. Most investigations of finfish and shellfish mariculture sites have shown effects from organic enrichment extending 20-45 m from the culture site (Mattsson and Linden 1983; Brown, Gowen and McLusky 1987). Weston (1990), however, found that although enrichment changed sediment chemistry to only 45 m from a farm, the effects on the benthic community were apparent to at least 150 m. The rates at which benthic conditions change after a farm is set up and the rate at which normal conditions return after removal of the farm will vary among sites, but it appears that disturbance occurs over a period of months while recovery requires several years (Weston 1991). In contrast, Frid and Mercer (1989) found no evidence of benthic enrichment from a caged-fish farm after three years of operation in an area of strong tidal flow. However, they warned of the possible accumulation of farm wastes in nearby sediment sinks and of the nutrient load to the water column. Sedimentation, together with shading effects from the cages, may cause localised denuding of seagrass beds (anon. 1992a).

The release of soluble inorganic nutrients (nitrogen and phosphorus) from intensive fish and prawn farming has the potential to cause nutrient enrichment and eutrophication (increase in primary production) of a water body (GESAMP 1991). Most examples of eutrophication caused by aquaculture have been found in freshwater, although it could occur in semi-closed coastal inlets and lagoons that have restricted exchange of water (GESAMP 1991). There is concern that intensive aquaculture in some lakes will alter the trophic state of the water bodies and result in the disappearance of native fish species (Korycka and Zdanowski 1981; Penczak et al. 1982). On the other hand, a mild degree of fertilisation may be beneficial to natural fisheries in nutrient-poor systems (Phillips et *al.* 1985).

In general, aquaculture activities increase density and species richness of wild fish fauna near culture operations (Weston 1991). Several studies report an increase in numbers of native fish next to cage farms (Hays 1980; Loyacano and Smith 1976; Kilambi et *al.* 1976). Kilambi et *al.* (1976) also found that the presence of cage culture improved survival and growth of certain wild species. In such cases, the culture site is likely to offer increased food availability (Phillips et *al.* 1985), provide structures for fish to congregate around (Gooding and Magnuson 1967), and to increase productivity (Weston 1991). Studies have shown that extensive cultivation of bivalves alters the food web by removing phytoplankton and organic detritus as well as by competing with other planktonic herbivores (GESAMP 1991).

Aquaculture, like other human activities, can disturb wildlife. Human activity can be disruptive to breeding areas and feeding grounds, while the aquaculture facility itself can attract predatory species (GESAMP 1991). If destructive methods are used to control these predatory wildlife, local populations might be adversely affected. In a study to determine the potential impact on birds of a proposed oyster farm in the Nooramunga region of Corner Inlet, Peter (1990) found that it was unlikely that oyster farming practices would affect bird species and that approval of the operation should not be prevented on ornithological grounds. However, he warned that the findings should apply only to that area and should not be used elsewhere in Corner Inlet. The reason given was that the avifaunal populations in this area were not as significant as in other areas of Corner Inlet.

Aquaculture operations may sometimes compete for space where rooted emergent and submerged vegetation occurs. Such areas are important for nursery grounds where predators can be avoided (Beveridge 1984).

The introduction of exotic species and the genetic consequences of interbreeding between cultured and wild populations can potentially have dramatic impacts that are usually irreversible (Weston 1991).

Detrimental effects caused by the introduction of exotic species include:

- population explosion of the introduced species, leading to competition with and eventual elimination of native species;
- introduction of new pests, diseases and parasites harmful to resident species (Rosenthal 1980)
- habitat destruction
- interbreeding (Folke and Kautsky 1989).

The traits selected for farmed fish may not be the traits needed to adapt to natural ecosystems. Escaped fish could interbreed with native fish producing progeny that are poorly adapted to the ecosystem. There is insufficient information available to judge whether this would have a serious ecological impact (GESAMP 1991); in fact, there is evidence that hatchery-reared salmonids do not compete well with wild populations of the same species (Fraser 1981; Bachman 1984). In contrast, Hindar, Ryman and Utter (1991) warn of being complacent about the possible genetic effects of cultured fish on natural populations, since recent studies are beginning to support theoretical concerns about this issue. Pierce (1990) highlights these concerns for Australian fisheries managers.

Without proper precautions, diseases can be easily introduced by transporting fish from other areas (Avault 1981). Sometimes the disease or parasite may have already been present in the wild fish but only reached abnormal levels when the density of fish increased or environmental conditions changed due to aquaculture (Beveridge 1984). In cage culture of trout and salmon, no specific diseases have been noted where there was an accumulation of wastes under the cages, but it appears that the fish are more vulnerable to disease problems in general and suffer higher mortality on such sites than fish held in cleaner sites (Phillips and Beveridge 1986).

Summary

- Deposition of food and faeces can change the indigenous biota.
- Release of nutrients may alter the trophic state of water bodies.
- Aquaculture activities tend to increase density and species richness of wild fish fauna.
- Aquaculture activities can be disruptive to breeding areas and feeding grounds of wildlife.
- Introduction of exotic and cultured species can affect indigenous biota.

8.3.5 Landscape values

Aquaculture facilities and activities can effect landscape values if they create visual intrusions or landscape scars. Nearby residents, user groups or even passers-by may be legitimately aggrieved if they suffer a loss of scenic value caused by introduced colours and forms that conflict with the natural elements of the wetland.

The visual sensitivity of a wetland landscape can be measured in terms of how well the natural characteristics can visually absorb or screen landscape changes brought about by the construction of any pondages, buildings, piping, roading, power supply structures and cages, or by activities associated with harvesting, water aeration, transportation etc. Coastal landscapes, for example, generally offer a poor visual absorption capability because the vegetation associated with this environment tends to be low and sparse.

To introduce human-induced changes responsibly to the landscape, it is important that the scenic qualities and the visual sensitivity of the area are accounted for in the design and operations of the aquaculture development. Refer to Chapter 3 Landscape Assessment.

Summary

- Aquaculture facilities and infrastructure can affect landscape values by introducing colours and forms that conflict with natural scenic views.
- It is necessary to take account of landscape values to facilitate the integration of any developments into the wetland landscape.

8.3.6 Water resources

The water resources of a wetland are valued for their biological productivity and diversity, the passive recreation opportunities they offer such as boating, game hunting and bird watching, their pollution-cleaning and nutrient-trap capabilities and their role in water flow regulation.

The resource can also serve agricultural needs or provide industrial and commercial uses including fish harvesting, salt production, water cooling for power stations or effluent treatment. The stresses placed on the water resource will depend on the combined requirements of all users and the extent to which the supply is manipulated.

The demands placed on the water resource by aquaculture or other fisheries will be largely determined by the methods of operation and the growth requirements of the culture species. In the case of an intensive off-stream operation, the potential impacts will be influenced by the volume and rate of intake water needed, site uses of the water, and treatment and disposal measures of the effluent discharge. In-stream operations may affect water resources by altering natural stratification processes, increasing turbidity and altering nutrient levels.

Wetlands often constitute a drainage base and, as such, are susceptible to groundwater discharge to that system. The transfer of groundwater to surface waters can occur when surface waters are reduced, or during periods of high infiltration, thus allowing the watertable level to migrate or flow to the surface. Instances where the water regime can be altered to allow discharge events include transporting local water off-site in live fish tanks; modifying the catchment area through landscape alterations; excessive evaporation caused by increasing the surface area in off-stream, shallow lagoons and use of aeration equipment; or deepening wetlands. The rising watertable can contain a high level of dissolved soil salts which may lead to increased salinisation of the surface water or the surrounding land.

Recharge events, where the transfer is from surface water to the groundwater resource, occurs mainly due to water percolating through the soils. Problems associated with groundwater management include depleted recharge, possible salt water intrusion and pollution of the groundwater resource by chemicals and nutrients.

Summary

- Changes to the water regime, such as modifying or depleting surface waters, can place stress on the water resource.
- Natural water resources should not be considered finite and authorities with resource management responsibilities should be aware of the implications of

- their management decisions on water production, utilisation and conservation.

8.3.7 Socio-economic effects

Direct socio-economic benefits from aquaculture include the commercial production of fish and related aquatic products, opportunities for employment and, in some instances, foreign exchange earnings. Depending on the scope of the aquaculture enterprise, it would normally be expected that indirect benefits could flow to other industries that provide operational or commercial support in the form of processing, transportation, marketing, technological services and administration.

Unfortunately, there have been many historical instances in the development of the aquaculture industry where such benefits have not been realised because inadequate planning and management guidelines have created or worsened ecological problems. The consequences of such unsustainable development have been significant socio-economic costs to the community, including large scale loss of wetland biodiversity, land subsidence, acidification, reduction in surface and ground water quality, loss of storm protection functions—even the displacement of rural communities dependent on these natural resource systems (GESAMP 1991, Chua 1992).

Poor water quality management in aquaculture could result in health threats to the public and pose serious socio-economic problems. Heavy metals and other toxic chemicals may be accumulated by bivalves or fish grown in conditions where the waters are contaminated with industrial and agricultural wastes. Pathological cases have been reported from the consumption of fish products with high contents of mercury, cadmium, arsenic, lead and chromium (Arai 1991).

Potentially adverse socio-economic effects of aquaculture can be minimised by applying appropriate environmental controls in the planning and management of the operation. These measures should ensure that the economic, social and environmental values of the development are maximised for the net benefit to the community—the underlying principle of ESD management.

To derive a balance between the economic, social and environmental benefits that ensure sustainable development requires that the value of these benefits can be measured on a comparable scale. This can be done by considering their respective contributions in a cost-benefit framework, a concept where both cost and benefit may be seen as the respective loss or gain in community welfare values. These values can usually be measured in either *direct monetary* terms ('gains' can be expressed in improved market prices for fish produce or tourist dollars gained from wetland improvements while 'losses' might include costs associated with cleaning up chemical spills, losses caused to agricultural productivity, costs to counter land subsidence, financial costs of development etc.) or in *indirect* ***monetary*** terms ('gains' may be the intrinsic value of the wetland for birdwatchers or in knowing that wetland assets are simply conserved for either the current generation or the next; 'losses' could be where the optional or potential use of the wetland to the community is no longer available, or it may be measured in reduced visual aesthetics).

Placing a dollar value on the *direct monetary* costs and benefits associated with the commercial use of natural resources is relatively straightforward. The market valuation of *indirect monetary* costs and benefits is much more complex, but possible. A technique that is finding acceptance is known as 'contingent valuation' (CV). Stone (1991) applied this method with some success to measure the non-market values of the Barmah wetlands in Victoria. It has the particular advantage over other non-market valuation techniques in that it is able to account for both non-use and use component of the *indirect monetary* value.

Summary

- Aquaculture can provide socio-economic benefits for the community by generating income and employment.
- Environmental controls safeguard against adverse socio-economic impacts.
- Factors that contribute to community welfare values (economic, social and environmental effects) should be accounted for equally in the decision-making process to ensure sustainable development.

8.4 CONFLICTS BETWEEN AQUACULTURE AND OTHER VALUES

8.4.1 Recreation, tourism and aesthetic values

Wetlands are valuable public areas for many different types of activities, such as boating, fishing, hunting, photography, sightseeing and studying nature. Conflicts can arise even between these public uses. Aquaculture will often have both a negative and positive effect on these activities. In many situations, the conflicts with aquaculture will arise out of the impacts already discussed. For example, fishing could be affected by the escape of exotic species that may alter the population of indigenous species. In other situations, aquaculture facilities can restrict access to the water and interfere with safe anchorage and with movement on the water. On the positive side, aquaculture operations may enhance fish stocks and increase numbers of some waterbirds by improving productivity and providing additional habitat.

8.4.2 Other commercial uses

If aquaculture operations are not effectively managed by owners or controlled by authorities, the possible adverse environmental impacts previously discussed could affect other commercial activities such as agriculture and commercial fisheries. Particularly important are the concerns about transfer of diseases, changes in genetic resources, and competition for broodstock and seedstock (anon. 1992b). Aquaculture might also compete for water resources needed for crops and stock. This competition could become intense in areas where aquaculture demands are greatest at times of minimum water availability (Phillips *et al.* 1991). Aquaculture could sometimes compete for space, particularly where commercial fishing takes place.

8.5 WISE USE OF WETLANDS

Aquaculture in wetlands has the potential to produce food for people and to generate income that will contribute to social and economic well-being (GESAMP 1991). However, developments must proceed wisely to make sure that financial gain is not at the expense of the ecosystem or the rest of society.

Wise use implies sustainability in the utilisation of natural resources. The wise use of aquaculture in wetlands requires that operations are ecologically acceptable and sustainable, economically sound and ethical. Similarly, sustainable development (in the agriculture, forestry and fisheries sectors) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable (FAO 1988). In particular, sustainable aquaculture requires wise management of water resources, so that water is not wasted and its quality is assured (Pullin *et al.* 1992). For other fisheries, the wise use of resources involves the harvesting of fish without adversely affecting the wetlands upon which they depend (Leadbitter and Doohan 1991).

The risks of aquaculture must be predicted and evaluated, and measures formulated to contain them within acceptable, pre-determined limits (GESAMP 1991). This is not an easy task. Looking at only one aspect, Alabaster (1982) suggested that fixed emissions standards should not be rigidly set because the environmental impact of effluent discharge is dependent upon the quality and quantity of receiving waters. He also stated that this was true even when considering the requirements of a single type of aquaculture. Each case must therefore be evaluated separately and continuously monitored.

There are many important factors to consider when developing environmentally and socially acceptable commercial use of wetlands; some are listed below.

Proposals and procedures

- Developers must deal with public concerns. In their written proposals, fish culture permit applicants should be required to identify and indicate how they propose to address public (and agency) concerns.
- Preferential treatment must not be given unfairly to individuals or organisations when allocating public resources.
- Mechanisms must be available for enforcement activities, such as monitoring legal and illegal stockings.
- Unsightly developments should be avoided.

Genetic and ecological concerns

- Aquaculture development must not cause loss of or deleterious changes to the wild genetic resources of living organisms or their natural habitats (Pullin *et al.* 1992).
- Translocation of native animals beyond their natural range and of exotics to new habitats should be carefully and rigidly controlled (GESAMP 1991). A Code of Practice should be developed and followed. Control of translocations requires a mixture of policies, regulations and conditions built into the permit

system. The likely consequences of organisms escaping should be thoroughly evaluated before any aquaculture proceeds (Pullin *et al.* 1992).

- Any in-stream aquaculture operations should allow for migration of aquatic organisms.
- It is essential to monitor for ecological change and modify operations if the change is unacceptable.

Management practices

- A Code of Practice should be followed to control the use of bioactive compounds, including antibiotics and pesticides, to prevent misuse (GESAMP 1991) and subsequent short-term or long-term damage. Controlling the use of bioactive chemicals requires a mixture of policies, regulations and conditions built into the permit system. Widespread routine use of drugs should be discouraged (Pullin *et al.* 1992). Diseases can be prevented by changing management practices rather than relying on chemical treatment (Purser 1993). The use of bioactive compounds can lead to resistant diseases in indigenous wild populations.
- Management practices must minimise wastage of food, build-up of sediments, and risks from diseases.
- The establishment of a comprehensive disease monitoring program, using qualified staff, and a stock movement register would greatly reduce the potential for serious disease outbreaks (anon. 1992a).
- All organisms stocked should be purchased or obtained from a legal source, preferably with certification of being disease free.
- Discharges should be regulated and clean-up practices enforced. Levels adopted should be within the assimilative capacity of receiving waters (GESAMP 1986).
- In monitoring effluent discharges, Alabaster (1982) recommends:
  - collecting sufficient number of representative samples of both effluent and influent;
  - taking samples over periods of 24 hours and during periods of low flows;
  - unity of monitoring approaches: time, frequency, location, parameters, methods (eg BOD with or without settlement, inhibition of nitrification).
- Wastewater re-use should be encouraged where possible.
- Control of predatory wildlife should be adequate and minimise the need for destruction by legal or illegal methods.
- Use of trained staff should be encouraged.

8.5.1 Aquaculture in wetlands—the decisions

The following questions should be considered when evaluating proposals for aquaculture developments in wetlands.

Initial decisions

- Are the expected impacts acceptable for this classification of wetland?
- Are the benefits worth the risk?
- What is the current condition of the wetland?

- What are the objectives for its management?

Site

- What is the ownership status of the land or water?
- What is the classification of the wetland? Is it a declared nature conservation reserve or part of a critical habitat?
- Are there any threatened species or habitats at this site? What is the expected effect on these?
- Is the wetland a designated 'culture water'? (as listed in the Second Schedule of the *Fisheries (Eel) Regulations* 1992)
- What agency controls the site?
- Who owns the access and controls the traffic to the site?

Description of operation

- What amounts of water and land are required?
- Will the natural flow regime or water levels be altered?
- Will additional water be required? What is the source and quality of that water?
- Will the system be extensive or intensive?
- What is the stocking density?
- Will enclosures be used?
- Will artificial feeds be used?
- Is the operation secure? What are the safeguards against escape of stock?
- What water quality parameters will be monitored and how often?
- What are the expected quality and volumes of effluent, and times and places of discharge? How will suspended solids be settled out and sludge disposed of? What is the size of the disposal area?
- Are water re-use systems planned?
- What are the proposed disease management practices? Can the site be isolated?

Environmental impact

- Is there sufficient information to assess the operation's potential environmental effect? If so, does the operation meet the environmental requirements of the EPA and all other agencies involved?
- What are the likely impacts of this type of aquaculture?

Target species

- Is the species endangered?
- Is the species indigenous to the water catchment?
- Is the species noxious?
- Is this species permitted to be stocked in this area?
- Can the stock be obtained from legal sources? Is the species on the illegal import list?
- Is the culture of this species viable?
- Are there any alternative and more viable species available?

- If a native species, can the genetic variability of the wild stock be maintained?
- If an exotic species, will this species harm the environment if it escapes?
- Can this species establish a self-sustaining population at this site?
- What are the disease risks? Does the stock have a health certification? Can safeguards be put in place?
- Are sterile stock available?

Economics

- Are the real costs of production known?
- Have markets been established or shown to be feasible?
- Are sufficient funds available to ensure that risks will be minimised?
- How likely is the business venture to succeed?

Conflicting uses

- Are there any other commercial activities in this wetland? How will this operation affect those activities?
- Are there any recreational activities in this wetland? How will this operation affect those activities?
- Are there any objections to this operation? How will objections be sought and dealt with?

Summary

Aquaculture and other fisheries should be permissible in wetlands provided the possible effects are known and acceptable. It is important to develop a policy framework that clearly states what is acceptable and what is not. The decision-making process for approving the use of wetlands for these purposes should be consistent with these policies.

8.6 REFERENCES

Alabaster, J.S. 1982. Report of the EIFAC Workshop on fish-farm effluents. Silkeborg, Denmark, 26-28 May 1981, *EIFAC Technical Paper 41.*

—— 1992a, Aquaculture and the environment. Technical paper No. 5. In: *Draft National Strategy on Aquaculture: Technical Papers for Discussion.* Australian and New Zealand Fisheries and Aquaculture Council.

1992b. Relationship between wild fisheries and aquaculture. Technical paper No. 2. In : *Draft National Strategy on Aquaculture: Technical Papers for Discussion.* Australian and New Zealand Fisheries and Aquaculture Council.

Aoki, T. 1989. Ecology of antibiotic-resistant determinants of R plasmids from fish pathogenic bacteria. In : Hattori, T., Maruyana, Y., Morita R.Y. and Uchida A. (eds). *Recent advances in microbial ecology.* Japan Scientific Societies Press, Tokyo, Japan.

Aoki, T., Jo, Y. and Egusa, S. 1980. Frequent occurrence of drug resistant bacteria in Ayu *(Plecoglossus altivelis)* culture. *Fish Pathology* 15 (1):1-6.

Arai, T. 1991. Chemical and microbial contamination of fisheries products. In Fish health management in Asia-Pacific, Report on a regional study and workshop on fish disease and fish health management *(ADB/NACA),* ADB. *Agriculture Department Report Series No.* 1. Bankok, Thailand, pp. 435-439.

Austin, B. 1985. Antibiotic pollution from fish farms: effects on aquatic microflora. *Microbiological Sciences* 2 (4):113-117.

Avault, J. Jr. 1981. Prevention of fish diseases-some basics. *Aquaculture Magazine* 7 (5):40-41.

Bachman, J.W. 1984. Foraging behaviour of free-ranging wild and hatchery brown trout in a stream. Trans. *Am. Fish. Soc.* 113:1-32.

Beveridge, M.C.M. 1984. Cage and pen fish farming: Carrying capacity models and environmental impact. *FAO Fisheries Technical Paper No. 255.*

Beveridge, M.C.M., Phillips, M.J. and Clarke, R.M. 1991. A quantitative and qualitative assessment of wastes from aquatic animal production. In : Brune D.E. and Tomasso J.R. (eds). *Aquaculture and Water Quality. Advances in World Aquaculture 3.* The World Aquaculture Society, Louisiana, USA.

Brown, J.R., Gowen, R.J. and McLusky, D.S. 1987. The effect of salmon farming on the benthos of a Scottish sea loch. *Journal of Experimental Marine Biology and Ecology* 109:39-51.

Bullock, G.L., Stuckey, H.M., Collias, D., Herman, R.L. and Maestrone, G. 1974. In-vitro and in-vivo efficacy of a potentiated sulphonamide in control of furunculosis in salmonids. *J. Fish. Res. Bd. of Can.* 31:75-82.

Chua, T.E. 1992. Coastal aquaculture development and the environment: The role of coastal area management. *Mar. Pollution Bull* 25:98-103.

Eng, C.T., Paw, J.N. and Guarin, F.Y. 1989. The environmental impact of aquaculture and the effects of pollution on coastal aquaculture development in Southeast Asia. *Marine Pollution Bull.* 20 (7):335-343.

Fisheries and Agriculture Organisation 1988. *Aspects of FAO's Policies, Programmes, Budget and Activities Aimed at Contributing to Sustainable Development.* Ninety-fourth Session of the FAO Council, Rome, CL 94/6.

Folke, C. and Kautsky, N. 1989. The role of ecosystems for a sustainable development of aquaculture. *Ambio* 18 (4):234-243.

Ford, K. and Robertson, C. 1995. Prawn farm effluent: yes it can be successfully managed. Austasia Aquaculture 9 (2):33-34.

Fraser, J.M. 1981 Comparative survival and growth of planted wild, hybrid and domestic strains of brook trout (Salvelinus *fontinalis*) in Ontario Lakes. Can. *J.* Fish. Aquat. Sci.. 38:1672-1684.

Frid, C.L.J. and Mercer, T.S. 1989. Environmental monitoring of caged fish farming in macrotidal environments. Marine Pollution Bulletin 20 (8):379-383.

GESAMP 1991. Reducing environmental impacts of coastal aquaculture. Reports and Studies No. 47. (IMO / FAO / Unesco / WMO / WHO / IAEA / UN / UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution).

Gladwin, R. 1992. Goals and principles of ecologically sustainable development and a summary of progress. In : Ecologically Sustainable Development of Victoria's Fisheries: Proceedings of a Conference at *Queenscliff,* Victoria, 21-23 September, 199. Department of Conservation and Natural Resources, Victoria, pp. 8-11.

Gooding, R.M. and Magnuson, J.J. 1967. Ecological significance of a drifting object to pelagic fishes. Pacific Science. 21:486-497.

Hays, T. 1980. Impact of net pen culture on water quality and fish population on Bull Shoals Reservoir. Completion Report: Arkansas Game and Fish Commission, USA.

Hindar, K., Ryman, N. and Utter, F. 1991. Genetic effects of cultured fish on natural fish populations. Canadian I. Fisheries and Aquatic Sciences 48:945-957.

Jacobsen, P. and Berglind, L. 1988. Persistence of oxytetracycline in sediments from fish farms. Aquaculture 70:365-370.

Kilambi, R.V., Hoffman, C.E., Brown, A.V., Adams, J.C. and Wickizer, W.A. 1976. Effects of cage culture fish production upon the biotic and abiotic environment of Crystal Lake Arkansas. In : Final Rep. Arkansas Game Fish Comm. U.S. Dep. Commerce. NOAA/NMFS PL 88-309 Project 2-166R Dept. of Zoology, University of Arkansas.

Korycka, A. and Zdanowski, B. 1981. Some aspects of the effects of cage fish culture on lakes, with special reference to heated lakes. In: Tiews K. (ed.). Aquaculture in Heated *Effluents* and Recirculation Systems. Heenemann Verlagsgesellschaft, Berlin, FRG, pp. 131-37.

Leadbitter, D. and Doohan, M. 1991. Wise use of wetlands: Sustaining our fish harvest. In : Donohue R. and Phillips B. (eds). Educating and Managing for Wetlands Conservation : Proceedings of the Wetlands Conservation and Management Workshop. Australian National Parks and Wildlife Service, pp. 133-42.

Loyacano, H.A., Jr. and Smith, D.C. 1976. Attraction of native fish to catfish culture cages in reservoirs. Proceedings of the Annual Conference of Southeastern Association of Game and Fish Commissioners 29:63-73.

Mattson, J. and Linden, 0. 1983. Benthic macrofauna succession under mussels, Mytilus edulis L. (Bivalvia), cultured on hanging long lines. Sarsia 68:97-102.

Pearson, T.H. and Rosenberg, R. 1978. Macrobenthic succession in relation to organic enrichment and pollution on the marine environment. Oceanography and Marine Biology Annual Review 16:229-311.

Penczak, T., Galicka, W., Molinski, M., Kusto, E. and Zalewski, M. 1982. The enrichment of a mesotrophic lake by carbon, phosphorus and nitrogen from the cage aquaculture of rainbow trout, Salmo gairdneri. Journal of Applied Ecology 19:371-393.

Peter, J. 1990. Bird Study in Nooramunga: the Possible Effects of Oyster Farming. Royal Australian Ornithologists Union Report No. 74.

Phillips, M.J. and Beveridge, M. 1986. Cages and the effect on water conditions. Fish Farmer 9 (3):17-19.

Phillips, M.J., Beveridge, M.C.M. and Clarke, R.M. 1991 Impact of aquaculture on water resources. In Brune D.E. and Tomasso J.R.(eds). Aquaculture and Water Quality. Advances in World Aquaculture 3. The World Aquaculture Society, Louisiana, USA, pp. 568-591

Phillips, M.J., Beveridge, M. and Ross, L.G. 1985. The environmental impact of salmonid cage culture on inland fisheries: present status and future trends. *J.* Fish Biol 27(Suppl. A):123-137.

Phillips, M.J., Clarke, R. and Mowat, A. 1993. Phosphorus leaching from Atlantic salmon diets. Aquacultural Engineering 12:47-54.

Pierce, B.E. 1990. Biological impacts of translocations on North American salmonids, or, How to use the latest U.S. fisheries management techniques to decimate otherwise useful fisheries. In : Pollard D.A. (ed.). Introduced and Translocated Fishes and their Ecological Effects. Australian Society for Fish Biology Workshop 24-25 August 1989. Bureau of Rural Resources Proceedings No. 8, AGPS, Canberra, pp. 127-135.

Pullin, R.S.V., Rosenthal, H. and Maclean, J.L. (eds) 1992. Environment and aquaculture in developing countries. Summary report of the Bellagio Conference on Environment and Aquaculture in Developing Countries. International Center for Living Aquatic Resources Management, Conference Proceedings, No. 36.

Purser, J. 1993. Minimising the organic, inorganic and chemical impacts of salmon seafarms. Austasia Aquaculture 7 (2):34-36.

Rosenthal, H. 1980. Implications of transplantations to aquaculture and ecosystems. Marine Fisheries Review 42:1-14.

Samuelsen, O.B. 1989. Degradation of oxytetracycline in seawater at two different temperatures and light intensities and the persistence of oxytetracycline in the sediment from a fish farm. Aquaculture 83:7-16.

Schink, R.A. 1991. Chemicals for worldwide aquaculture. In: Fish health management in Asia-Pacific. Report on a regional study and workshop on fish disease and fish health management (ADB/NACA). ADB Agriculture, Department Report Series No. 1. Bankok, Thailand, pp. 441-67.

Schroeder, G.L. Alkon, A. and Laher, M. 1991. Nutrient flow in pond aquaculture systems. In : Brune, D.E. and Tomasso, J.R. (eds). Aquaculture and Water *Quality:* Advances in World Aquaculture 3. The World Aquaculture Society, Louisiana, USA pp. 489-505.

Stone, A. 1991. Economic Evaluation of wetlands. Wetlands Conservation Report Series, No. 1. Department of Conservation and Natural Resources, Victoria.

Warrer-Hansen, I. 1982. Methods of treatment of wastewater from trout farming. In: Alabaster, J.S (ed.). Report of the EIFAC Workshop on fish-farm effluent Silkeborg, Denmark, 26-28 May 1981. EIFAC Technical Paper No. 41, pp. 113-21.

Weston, D.P. 1990. Quantitative examination of macrobenthic community changes along an organic enrichment gradient. Marine Ecology 61:233-44.

Weston, D.P. 1991. The effects of aquaculture on indigenous biota. In: Brune, D.E and Tomasso, J.R. (eds). Aquaculture and Water Quality. Advances in World Aquaculture 3. The World Aquaculture Society, Louisiana, USA, pp. 534-67.

4.3 All primary field data collected during an evaluation should be provided to the managers of the appropriate CNR databases (e.g. Flora and Fauna Branch Wetlands Data Base; CNR Wildlife Atlas; CNR Flora Data Base).

4.4 Information on flora and fauna populations should be cited as a percentage of the total species population. Actual numbers of species recorded should be included in an appendix to the evaluation.

4.5 Priority for planning, management, works and allocation of funds will be given to wetlands that meet the important wetland criteria (Appendix 9a).

5. Procedures

5.1 The CNR Area Functional Manager will ensure that all potentially important wetlands are evaluated against the criteria (Appendix 9a and 9b) and using the evaluation pro forma (Appendix 9b).

5.2 The CNR Area Functional Manager will ensure that all relevant information required for the evaluation of a wetland is obtained and considered. Information from the Wetland Minimum Data Sets (Wetlands Data Bases established for the former CNR Regions), Corrick Classification (Govt of Vic. 1988), other available literature (refer to Malcolm 1991), other CNR databases, CNR officers, interest groups and elsewhere should all be used wherever possible. All sources must be fully and accurately cited. Refer to Appendix 9a for more detail.

5.3 The CNR Area Functional Manager will ensure that evaluations include maps indicating the boundaries of wetlands and highlighting important features.

5.4 The CNR Area Functional Manager will submit the completed evaluations to the Parks and Reserves Policy Section, National Parks and Reserves Branch.

5.5 The Manager, Parks and Reserves Policy Section will ensure that evaluations are entered into the Flora and Fauna Branch Wetlands Data Base and are provided to the Wetlands Unit of ANCA for incorporation in the Directory.

5.6 The Area Functional Manager will ensure that the results from wetlands evaluations are taken in to consideration in planning, management and works.

5.7 Additional information required to prepare site evaluations can be provided by the Parks and Reserves Policy Section, National Parks and Reserves Branch.

6. References

Commonwealth of Australia (1993) *A Directory of Important Wetlands in Australia,* Australian Nature Conservation Agency, Canberra.

Government of Victoria (1988) *Wetlands Conservation Program for Victoria* Department of Conservation, Forests and Lands, Water Victoria and Ministry for Planning and Environment.

Malcolm, J. (1991) Wetlands Bibliography (particularly Ramsar wetlands): a report to the Wetlands Unit, National Parks and Public Lands. Department of Conservation and Environment (unpublished)

7. Legislation

Sections 17 and 18 of the *National Parks Act 1975* (Vic.) state that the Director shall ensure that sufficient measures are taken to protect each area managed under the Act.

The *Wildlife Act 1975* (Vic.), *Forests Act 1958* (Vic.) and the *Crown Land (Reserves) Act 1978* (Vic.) provide the legislative basis for the management of wildlife reserves, State forests and Crown reserves respectively.

The *Flora and Fauna Guarantee Act 1988* (Vic.) provides for the protection of flora, fauna and communities.

Section 20(1)(c) of the *Catchment and Land Protection Act 1994* (Vic.) states that a land owner must take all reasonable steps to protect water quality, quantity and rate of flow on their land. Section 3 defines, for the purposes of the legislation, the land owner with respect to Crown land as: the occupier, under a lease, licence or other right; the Director of National Parks for areas reserved under the National Parks Act; or the Minister or public authority responsible for managing the land.

Section 5.7(1) of the *Wildlife (State Game Reserve) Regulations 1994* provides for the setting aside of areas for certain purposes including the conservation of wildlife, the planting or re-establishment of trees or vegetation etc.

8. Cross references to other procedural documents

11.3LW	Livestock grazing in wetlands 05-20-0736-1
11.5PL	Restoration of wetlands 02-20-0727-2
11.6PL	Managing water in wetlands 02-20-0728-2

Appendix 9a Criteria for Determining Nationally Important Wetlands (1995)

The following criteria for determining important wetlands in Australia are based on those developed by the former CONCOM Working Group on International Agreements relating to Migratory Birds and Wetlands as used in the first edition of *A Directory of Important Wetlands in Australia.* The criteria were revised by the ANZECC Wetlands Network at their first meeting in August 1994.

A wetland may be considered nationally important if it meets at least one of the following criteria:

1. It is a good example of a wetland type occurring within a biogeographic region in Australia.
2. It is a wetland which plays in important ecological or hydrological role in the natural functioning of a major wetland system/complex.
3. it is a wetland which is important as the habitat for animal taxa at a vulnerable stage in their life cycles, or provides a refuge when adverse conditions, such as drought, prevail.
4. The wetland supports 1% or more of the national populations of any native plant or animal taxa.
5. The wetland supports native plant or animal taxa or communities which are considered endangered or vulnerable at the national level.
6. The wetland is of outstanding historical or cultural significance.

The criteria are to some extent subjective and open to interpretation. The following guidelines aim to provide assistance in standardising the application and interpretation of the criteria nationally.

Ramsar definition of a wetland

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, to the depth of which at low tide does not exceed six metres.

Guidelines for applying the criteria

1. *It* is a <u>good example</u> of a <u>wetland type</u> occurring within a <u>biogeographic region</u> in Australia.

- 'Good example' relates to the character of the wetland in relation to: its condition (in terms of natural state), unusual occurrence in the area, uniqueness and/or level of representation within the bioregion eg. the wetland type may be common within a bioregion but it is a good example because it has maintained its ecological character and condition better than other examples.
- 'Wetland type' is based on the wetlands classification system used for the first edition of the *Directory of Important Wetlands in Australia (see* Attachment A) but has been modified as agreed by the Network. List all wetland types

present within the boundaries of the site, indicating the most dominant wetland type if possible.

- Assess the wetland within the 'biogeographical regions' identified in the Interim Biogeographic Regionalisation for Australia (IBRA). Where biogeographical regions cross state/territory jurisdiction borders, investigators must liaise with adjacent State or Territory ANZECC Wetlands Network representatives in establishing wetlands which qualify for inclusion under this criteria.

Examples:

a Buffalo Lake, Queensland: a shallow lake typical of a suite of lacustrine systems in the Karumba Plains province.

b Innot Hot Springs, Queensland: One of Queensland's few hot springs.

2. It **is a wetland which plays an <u>important ecological or hydrological role</u> in the natural functioning of a major wetland system/complex.**

- **The** site plays an important role in the natural functioning of a major river basin or coastal system, especially when it is located in a transitional position e.g. where river meets estuary.

- The wetland site is an integral element of the ecological / or hydrological process within the watershed. For example, controlling water quality, flooding regime, erosion control, groundwater discharge and recharge, storm protection, microclimate stabilisation of the system.

Examples:

a Ginini Flats, Cheyenne Flats, Morass Flats, ACT: A mosaic of peat bog, wet heath, wet herbfield, sedgeland, dry heath and tall wet heath.

b Barmah/Millewa Forest: River Murray Floodplain.

3. **It is a wetland which is <u>important</u> as the <u>habitat for animal taxa at a vulnerable stage in their life cycles,</u> or <u>provides a refuge</u> when <u>adverse conditions</u> such as drought prevail.**

- The wetland has special value because it provides important, critical, or necessary habitat for animal taxa at a vulnerable stage in their life cycle. vulnerable stage may include breeding/spawning, juvenile development, moulting and migratory animals reliant on specific stop-over sites.
- The wetland has special value because it supports an increasing population of different species when adverse conditions occur such as drought.

Example:

a Mary Floodplain System, Northern Territory: is a major breeding area (one of the most important) for Magpie Geese.

b Macquarie Marshes, New South Wales: provides breeding habitat for some 40 species of waterbirds following flooding.

c Mound Springs, South Australia: provide a refuge for many species during drought.

d Lake Eyre, South Australia: is a major breeding area of nomadic water birds during flooding.

4. **The wetland supports 1% or more of the national populations of any native plant or animal taxa.**

- **The** wetland supports at least 1% of the national population of a species.

Example:

a Western Port, Victoria: Supports Orange-bellied Parrot population.

b Lake Grace system, Western Australia: The count of 12,000 Banded Stilt in September 1984 is more than 1% of the national population.

5. **The wetland supports native plant or animal taxa or communities which are considered endangered or vulnerable at the national level.**

- The wetland must support one or more native plant or animal species or communities which are nationally endangered or vulnerable. The Commonwealth's *Endangered Species Protection Act 1992* (ESP Act) includes lists of nationally endangered or vulnerable fish, amphibians, reptiles, birds, mammals and vascular plant species. The lists are largely based on regularly updated lists as agreed by the Australian and New Zealand Environment and Conservation Council (ANZECC). Invertebrate and non-vascular plant species have not been listed, although ANCA is funding the preparation of national overviews on the status of species within these two groups. These are unlikely to be published within the timeframe of preparing revisions to the Director.
- National definitions for endangered, vulnerable, ecological communities are as follows:

  Endangered: A species or ecological community is endangered if: it is likely to become extinct unless the circumstances and factors threatening its abundance, survival or evolutionary development cease to operate; its numbers have been reduced to such a critical level, or its habitats have been so drastically reduced, that it is in immediate danger of extinction; or it might already be extinct, but it is not presumed extinct. In addition, a species may be regarded as endangered if at any stage of its biological development it is difficult to visually differentiate it from an endangered species.

  Vulnerable: A species is vulnerable at a particular time if, within the next 25 years, the species is likely to become endangered unless the circumstances and factors threatening its abundance, survival or evolutionary development cease to operate. In addition, a species may be regarded as vulnerable if at any stage of its life cycle it is difficult to visually differentiate from a vulnerable species.

  An ecological community is an integrated assemblage of native species that inhabits a particular area in nature.

  Native species means a species indigenous to Australia including those species indigenous to the continental shelf of Australia, its coastal sea and those species that may visit these areas occasionally or periodically.
- For the purposes of the revised Directory, it is proposed that the following lists are used to determine the status of threatened species:

  —*Threatened Australian Flora,* prepared by ANZECC Endangered Flora Network, June 1993 (copy attached, further copies available from ANCA);

—latest version of the ANZECC list *Threatened Australian Vertebrate Fauna.* This is to be updated at the end of March 1995, copies to be circulated at that time.

- As indicated, ANZECC lists of endangered and vulnerable species are continually being revised. In some cases, an argument can be made that a particular species should be recognised as nationally endangered or vulnerable even though it has not been added to the ANZECC list. When such issues arise, ANCA should be consulted.

Example:

a Daly-Reynolds Floodplain-Estuary System, Northern Territory: False Water Rat *Xeromys myoides* (vulnerable).

6. The wetland is of outstanding historical or cultural significance.

- *'Outstanding', 'well renowned', 'prominent'* historical or cultural characteristic/feature of wetland judged at a state and/or national level.
- Historical and/or cultural values relate to significant Aboriginal or non-Aboriginal activities within the area that have been recorded in the history of the region and have potential significance to the State/Territory and/or nation.
- Concerning Aboriginal cultural significance, it should be noted that wetlands by their nature are almost always significant at a local level to Aboriginal communities. They are, or were, important sources of food and fibre, often associated with spiritual beliefs, and very often used as burial sites. It is suggested that wetlands should only be listed for cultural significance to Aboriginal people where there is good evidence, for example on advice from local Aboriginal communities or results of archaeological surveys.
- This criteria suggests that the wetland did have, or still has, substantial value in supporting human communities by the provision of food, fibre, or fuel; maintaining cultural values or supporting food chains, water quality, flood control or climate stability. Listing under this criteria should not occur where such activities are ongoing but are not sustainable and/or where adverse change of ecological character is occurring as a result.
- Additional activities associated with historical and/or cultural values may include: tourism, recreation, scientific research, education, grazing, water supply, fisheries production, etc., assuming they are undertaken in an ecological sustainable way. Again there should be strong evidence of such significance to warrant listing under this criteria.

Examples:

a Tourism: Mataranka Thermal Pools, Northern Territory. The pool attracts 150,000 visitors annually.

b Recreation: Shallow Inlet Marine and Coastal Park, Victoria. Area offers a variety of recreational activities.

c Education: Herdsman Lake, Western Australian. The Herdsman Study Centre.

d Scientific Research: Western Port, Victoria - 'one of the world's first comprehensive studies of an ecosystem.'

e Cultural/Historic: Dalhousie Springs, SA. A favourite camping place for Aboriginal people, also significant location for Adelaide-Darwin telegraph line.

f Cultural: Nursery Swamp, ACT. An Aboriginal quarry and paintings occur at the site.

g History: Dumbleyung Lake, WA. Sir Donald Campbell broke world water speed record on the lake in 1964.

h Fisheries: The Broadwater, New South Wales - important habitat for many commercial fish species.

In the case of large and complex wetland systems, two levels of approach may be advisable: a broad approach for the system as a whole, and a more detailed approach for key localities within the system.

Appendix 9b Pro forma and Guidelines for Preparing Individual Site Evaluations

Name of wetland: The name of the site and its reference number (format: centred, bold and positioned above site information).

Location: Include latitude and longitude of the approximate centre of the wetland expressed in degrees/minutes/seconds. If the site consists of two or more discrete entities, the centre coordinates of each of these entities should be given. A general description of the location of the wetland including the distance of the wetland in relation to nearest landmark, town, reserve or access point. Bioregion name; local council district.

(Note: Marine equivalents of terrestrial biogeographic regions are not yet finalised. Wetland listings associated with marine areas should be included under the adjacent terrestrial biogeographic region.)

Area: in hectares.

Elevation: in metres above sea level (m ASL).

Other wetlands in same aggregation: listed by reference number.

Wetland type: List all wetland habitats present in the site using the wetland classification system. Written description together with the identifying code. Give an indication of the dominant wetland type.

Criteria for inclusion: Reference numbers for criteria used to justify listing of wetland.

Site description: identify important characteristics of the site. This provides an opportunity to describe values which relate to the criteria used to select the area for inclusion—that is expand/justify the values that meet the criteria. Provide a brief summary of the site, two to three lines before describing physical, ecological and hydrological features under sub-headings. Subheadings are:

Physical features: a short description of the principal physical characteristics of the site, covering the following points where relevant: landform, geology, geomorphology, origin, soil types and climate including rainfall and evaporation.

Hydrological features: a brief description of the principal hydrological features such as source of water supply, maximum water depth, persistence, salinity regime and pH values. Other features may include the role of the wetland in recharge and discharge of ground water, flood mitigation, and maintenance of water quality.

Ecological features: a brief description of the main habitat, listing dominant plant communities, species present and describing seasonal variation and long term changes in species composition. Include information on adjacent areas where appropriate, to put the wetland in context.

Significance: Briefly outline the significance of the site/wetland type within the bioregion. Address the following sub-headings:

Notable flora: Threatened species: list threatened flora at national or state level that occur on the site. Always include scientific name in italics, followed by appropriate code of threat status in brackets (i.e. nationally Ne or Nv or State Se, Sv, or Sr as appropriate) e.g. *Cynanchum elegans* (Nv). Common name may be included before scientific name where there is one (often note the case for endangered flora). composition: include information on the composition of any plant species or communities for which the wetland is particularly important (local endemics or good examples of native plant communities).

Notable fauna: Threatened species: list threatened fauna at national or state level that are present at the site. Always include common name, scientific name (italics) followed by status code, where appropriate, in brackets (i.e. nationally Ne or Nv or State S plus code e, v, r) e.g. Little Tern, *Sterna albifrons* (Ne). composition: include information regarding composition of important fauna that may inhabit wetland permanently or seasonally. Important fauna include those which are migratory. An indication of population sizes, breeding colonies, migration stopover, etc. is also relevant.

Social and cultural values: describe social and/or cultural aspect or activities associated with the wetland. Social values may include tourism, recreation, scientific research, education, grazing, water supply, fisheries production, etc. Cultural values include specific historical associations whether they relate to Aboriginal or non-Aboriginal culture.

Land tenure: Where possible use standardised land tenure categories (refer Attachment B). Tenure should be addressed under the following sub-headings:

On site: Details of land ownership of the wetland site.

Surrounding area: Details of tenure type which is dominant in the surrounding areas if possible.

Current land use: Where possible use standardised land use (refer Attachment B). Land use should be addressed under the following sub-headings:

On site: current human use of designated wetland area.

Surrounding area: human use on land adjacent to the wetlands, and more broadly in the surrounding catchment.

Disturbances or threats: Disturbances of threats are defined as any direct or indirect human activities at the site or in the catchment area that may have a detrimental effect on the ecological character of the wetland. The effect may be a minor disturbance (e.g. low intensity grazing) or a major threat (e.g. water diversion schemes). Examples include disturbance by stock, diversion of water supplies, river regulation, siltation, drainage, pollution, excessive human activity, the impact of feral animals and plants, etc. A set of standardised threat categories is provided at Attachment B as a guide. Threats should be addressed under the following sub-headings.

Current: activities or features that are impacting on the wetland site at present. This should be written in a brief descriptive manner, using standardised terminology

(Attachment B) where possible. An indication of the severity or degree of threat may be given where known, e.g. moderate, low, etc.

Potential: potential future threats, for example planned changes in land use or degradation of site from current land use practices (e.g. increased salinity). Again, description should be consistent with standardised terminology where possible.

Conservation measures taken: Details of conservation measures being undertaken at the site, and where appropriate, the names of the protected areas established at or around the wetland. Where a management plan exists for a site, provide detail. Is it being implemented? Also include status in terms of Register of National Estate, Ramsar, Bioshpere Reserve and/or World Heritage where appropriate.

Management authority and jurisdiction: The name of the body directly responsible for the management of the wetland. Include regional/district office name where appropriate (this will make the document more useful for community groups and local government).

Compiler and date: The name of individuals and associated organisations (where applicable) who provided information for the site together with the date of compilation or that of the most recent update. If data has been updated the original compiler may be acknowledged.

9.3 WATER MANAGEMENT IN WETLANDS

CNR No: 02-20-0728-2
Originator: HULL, HAMER
Distribution: NPS GUIDELINES AND PROCEDURES MANUAL

1. Application

This guideline applies to water management in freshwater and non-marine saline and hypersaline wetlands managed by the Department of Conservation and Natural Resources (CNR). It may also be applied to estuarine wetlands affected by modifications to upstream (freshwater) water sources, and provides a basis for providing advice on the management of these wetland types on private land.

2. Background

The physical, chemical and biological functions which give wetlands their unique character and habitat value are largely influenced by the availability of water. Wetlands are maintained by hydrological processes, and play an important role in catchment hydrology.

Wetlands can alter naturally over time in response to tidal movements, seasonal or annual change or climatic events such as droughts and floods. Variations in water levels and regular or periodic drying of many wetland types (except for naturally permanent lakes) are necessary for natural wetland functioning (Briggs and Mahler 1985; Carter 1986); however, long-term disturbance to natural hydrological patterns can threaten the ecological health of wetlands.

European settlement and land use has led to the widespread modification of wetland hydrology through drainage, filling, salinisation, artificial and prolonged inundation, river channel modification, catchment deforestation and river regulation. Hydrological disturbance has been identified as one of the greatest historical and current threats to Victoria's wetlands.

Water management in wetlands needs to consider:

- the conservation status of the wetland (e.g. high value, Ramsar listed);
- the current water regime;
- any changes to the natural water regime that have taken place since settlement;
- human influences that currently or potentially influence hydrology;
- environmental water requirements;
- the need to alter the current water regime to meet management objectives;
- the details and costs of structures and works required to manage or manipulate water to achieve management objectives;
- monitoring programs.

3. Basis

This guideline is based on CNR's responsibility to preserve and protect natural, cultural and hertiage values on public land. It provides the basis for water management of wetlands in line with those responsibilities. It should be read in conjunction with relevant wetland hydrology texts (see Section 9). Although wetlands are found on most public land categories managed by CNR, the bulk are in parks and conservation reserves managed by the National Parks Service (NPS).

4. Guidelines

4.1 CNR will protect existing water regimes in naturally occurring wetlands where these maintain indigenous species and communities, ecological and hydrological processes and landscape character.

4.2 CNR will, as far as practicable, restore water regimes in naturally occurring wetlands to maintain indigenous species and communities, ecological and hydrological functions and landscape character.

4.3 CNR will manage disturbing and modifying agents and processes so that indigenous species and communities, ecological and hydrological functions and landscape character are maintained as far as possible.

4.4 CNR will give high conservation value wetlands priority when planning and implementating works required to manage water.

4.5 CNR will promote sound water management to the managers of other wetlands.

5. Procedures

5.1 General management

5.1.1 The Area Functional Manager is responsible for managing and protecting water regimes in wetlands consistent with this guideline.

5.1.2 Where the current water regime needs to be modified to fulfill a wetland's management objectives, or there is a conflict in the way water is managed, the Area Functional Manager may prepare a water management strategy (refer to Appendix 9a and 11.2LW Management planning for wetlands).

5.1.3 Where an approved management plan does not adequately address water issues, the Area Functional Manager will either revise/amend the plan or prepare a water management strategy (refer to Appendix 9c).

5.1.4 Where land owners are disadvantaged by works required to manage or restore water regimes in public wetlands, the Area Functional Manager may provide incentives to meet part of the costs of undertaking works or provide other assistance to foster co-operation.

5.1.5 The Area Functional Manager will provide access to water for stock in accordance with 11.3LW Livestock grazing in wetlands.

5.2 Environmental Bulk Water Entitlements

5.2.1 The Area Functional Manager (in consultation with the Area Flora, Fauna and Fisheries (FFF) Manager) may decide that an Environmental Bulk Water Entitlement is required to manage or maintain ecologically necessary water flows.

5.2.2 The Area FFF Manager is responsible for preparing a draft application for Environmental Bulk Water Entitlement. The Office of Water Reform can provide further advice.

5.2.3 The Area FFF Manager will forward the completed application to the Director, FFF Division.

5.2.4 The Director, FFF Division will either endorse the application and forward it to the Office of Water Reform or, where required, return the application to the Area Functional Manager for amendment.

5.2.5 The Office of Water Reform will endorse the application before forwarding it to the Minister for Conservation and Environment, the Minister for Natural Resources and representatives of the relevant water management authorities.

5.2.6 Once a Environmental Bulk Water Entitlement is secured, the Minister for Conservation and Environment will hold the title to the water allocation.

5.2.7 Costs for the purchase of water, purchase of surplus entitlements etc. will be negotiated on a case-by-case basis. Where existing regulation schemes have altered natural regimes, the relevant agent/agency will bear the costs of restoring the regimes. The costs associated with management and movement of water are currently being negotiated. For more information on costs, refer to the Waterways Unit, Catchment and Land Management Division.

5.2.7 Where a Bulk Water Entitlement is sought, and the management authority states that surplus flows are not available, there may be a case for the authority reviewing the management of the whole water supply (river) system. The cost of such investigations will need to be negotiated on a case-by-case basis.

6. Definitions

Environmental Bulk Water Entitlement. Having title or ownership of a given annual quantity of water or percentage of total water in a water system.

Environmental water requirement. The amount of water required over time to maintain the ecology of the wetland.

Water regime. The quality and quantity of water over time.

7. Legislation

Section 21(2) of the *Wildlife Act 1975* (Vic.) states that any person who without authority interferes with or damages any structures or interferes with the flow of water into, out of, or within a State wildlife reserve or nature reserve shall be guilty of an offence.

Section 3 of the *Flora and Fauna Guarantee Act 1988* (Vic.) defines a potentially threatening process as a process which may have the capability to threaten the survival, abundance or evolutionary development of any taxon or community of flora and fauna. Section 27 provides for the prohibition or regulation of any activity on land or in relation to the water that takes place within or outside critical habitat, and for the protection of critical habitat by works or activities.

Section 20(1)(c) of the *Catchment and Land Protection Act 1994* (Vic.) states that a land owner must take all reasonable steps to protect water quality, quanitity and rate of flow on their land. Section 3 defines, for the purposes of the legislation, the land owner with respect to Crown land as: the occupier, under a lease, licence or other right; the Director of National Parks for areas reserved under the National Parks Act; or the Minister or public authority responsible for managing the land.

Section 15 of the *Water Act 1989* (Vic.) relates to the unauthorised taking of water. Section 16 relates to the unreasonable and reasonable flow of water onto the land of another person. Section 20 describes whether a flow is reasonable or not reasonable.

Sections 36 and 40 provide for CNR to apply for a bulk entitlement of water. Section 43 specifies the conditions which may be applied when granting an entitlement.

Sections 52 and 53 provide for the Department to be licensed for the in-stream use of water. Section 67(1) provides for a person or authority to be licensed to undertake works to deviate a waterway.

Sections 202 and 208 relate to floodplain management. Section 218 relates to the flow of water in a drainage course. Sections 234 and 235 relate to water access with or without agreement of the land owner.

Section 23 of the *National Parks Act 1975* (Vic.) allows for works to be carried out for the protection of a park.

8. Cross references to other procedural documents

1.2P	Park management planning 05-20-0002-3
11.1 PL	Wetland evaluation 02-20-0710-2
11.2LW	Management planning for wetlands 02-20-0709-1
11.3LW	Livestock grazing in wetlands 02-20-0736-1
11.5PL	Restoration of wetlands 02-20-0727-2

9. References

Briggs, S.V. and Mahler, M.T. (1985) Limnological studies of waterfowl habitat in south-western New South Wales II: Aquatic macrophyte productivity. *Aust. J. Man. Freshw. Res.* 36:707-715.

Carter, V. (1986) An overview of the hydrologic concerns related to wetlands in the United States. *Canadian Journal of Botany* 64:364-374.

CNR-ANCA (in prep.) Manual of Wetlands Management Techniques. Department of Conservation and Natural Resorces and Australian Nature Conservation Agency.

Corrick, A.H. and Norman, F.I. (1980) Wetlands of Victoria I: Wetlands and waterbirds of the Snowy River and Gippsland Lakes catchment. *Proc. R. Soc. Vict.* 91:1-15.

Department of Water Resources (1989) Water for the Environment Stage 1, Guidelines for Incorporation of Environmental Water Requirements in Planning New Water Projects. Department of Water Resources, Victoria.

Appendix 9c Management of Water Regimes

Water regimes should be described quantitatively. The sophistication of the technique and level of detail should be appropriate to the wetland; generally, more sophisticated techniques should be employed for High Value wetlands, while rapid reconnaissance methods are adequate for other wetlands.

1. Determining current water regime

Water fluctuations

Describe the fluctuations in water level and the duration and extent of flooding and drying over time. This is probably the easiest information to record, and is the very least information required by wetland managers. The indices to describe water level changes will depend on the site characteristics, data availability, and management objectives. They should be quantitative and should include one or more of the following:

- number of independent floods per 100 years;
- mean, median and range of wetland water depth for each month;
- mean, median and range of duration of inundation;
- mean, median and range of duration of wetland dry periods;
- frequency histograms of months when the wetland was (i) wet and (ii) dry.

Hydrological type

Using an appropriate hydrological category, describe the wetland's hydrological type (Corrick and Norman 1980; CNR- ANCA in prep.).

Water budget

Quantify the wetland's water budget (water gains and losses over time). The water budget is made up of:

- evapotranspiration (the total evaporation from all water, soil, vegetation and other surfaces and plant transpiration. Evaporation from wetlands can be calculated using an evaporation pan and coefficient (refer to CNR-ANCA in prep) or by interpolation from climatic maps available from the Bureau of Meteorology;
- rainfall (daily, monthly and yearly rainfall are available from the Bureau of Meteorology. Long-term monthly average rainfall data will usually suffice;
- groundwater (inflow and outflow) (the process of groundwater exchange with wetlands is largely unknown, and difficult and costly to measure. The effort expended should match the significance of the wetland;
- surface flows (inflows and outflows) (these vary with the wetland type:

  i riverine floodplain wetlands: information on flows may be obtained from:
  - local river management authorities;
  - Rural Water Corporation;
  - Bureau of Meteorology, which maintains records for use in the State Flood Warning Scheme;

  - Victorian Surface Water Information to 1987 is a useful source of monthly data to 1987;
  - mathematical means (see CNR—ANCA in prep.).

ii shallow basin wetlands: these receive water from every storm that causes runoff (CNR—ANCA in prep.).

Degree of disturbance

Determine which elements of the water budget (if any) have been affected by disturbance, and the impact on the wetland in question. Disturbance will include:

- regional or catchment factors (e.g. the placement of dams and on-stream storages, river improvement, river channel incision or sedimentation, changes in groundwater behaviour or chemistry, increased infiltration rates, increased runoff);
- local factors (e.g. construction of levees, diversion of water, increased runoff, water extraction, loss of fringing vegetation, soil compaction).

Water quality parameters

The determination of E.C., pH, turbidity, temperature and available phosphorous are the minimum necessary requirements to establish a water quality profile of a wetland.

These measurements should be taken at regular intervals throughout a filling/drying cycle.

Assess the reliability of the data

The reliability, extent and representativeness of the data needs to be considered when interpreting the results (e.g. anecdotal data, seasonality etc.).

2. Determining the pre-settlement water regime

Where the water regime has been disturbed, the pre-European settlement water regime may be quantified by:

- examining historical hydrological records and topographic patterns;
- mathematical modelling based on a knowledge of the water budget;
- an investigation of remnant vegetation patterns and the requirements of key species. Remnants of woody species and, for recent changes, herbaceous species whose water requirements are known may provide a useful indication of the previous water regime.

3. Determining the preferred water regime

The preferred water regime must meet the water management objectives established by the management planning process. Where the current or pre-settlement water regimes do not meet these objectives, the preferred regime should be quantified using the parameters used to determine the current water regime (see 1 above).

4. Managing changes to water regimes

Where a change to the current water regime is required, and the preferred regime has been quantified, it should be implemented as soon as practicable after considering:

- the management options for bringing about the desired change;
- if there is legislative support for change, e.g. sections 16 and 208 of the *Water Act 1989* (Vic.), Section 21 of the *Wildlife Act 1975* (Vic.);
- the implications and effects of the desired change on adjoining landowners, water users and, where applicable, the downstream effects;
- options for minimising negative effects on adjoining landowners and other water users.

Where the desired change to the current regime cannot be achieved, the negative effects of the current regime should be minimised or off-set by:

- structural and engineering options to improve water management/ conservation;
- land acquisition;
- review of existing water releases and diversion regimes to identify opportunities to provide environmental flow requirements;
- buying back existing (unused or surplus) water entitlements;
- investigating cooperative agreements (e.g. a landowner is given an incentive to redirect drainage water, or a percentage of an individual's entitlement can be dedicated to the environment);
- investigating the possibility of dedicating 'spare' water that arises from efficiency gains from existing allocations to the environment e.g. through re-cycling, piping water supplied for agriculture or storing additional water in wet years;
- re-allocating water from existing users to the environment if and when water titles become available.

5. Monitoring

Wetland water monitoring projects involve measuring changes in water quantity and quality and biological communities. Technical advice and support is available through the National Parks and Reserves Branch of the National Parks Service and staff at the Water Resources Division and Rural Water Corporation.

Staff gauges, read monthly over a minimum of five years, provide a very useful profile of water level changes. Staff gauges should be established in as many wetlands as resources permit. Digital recorders are also available and these may be more efficient in remote situations or where detailed and continuous data is required. CNR—ANCA (in prep.) describes other techniques for determining the water level regime for each hydrologic type.

9.4 LIVESTOCK GRAZING IN WETLANDS (REVIEW)

CNR No:	02-20-0736-2
Originator:	HULL, HAMER
Distribution:	NPS GUIDELINES AND PROCEDURES MANUAL

1. Application

This guideline applies to all High Value wetlands, wetland-dedicated wildlife reserves, lake reserves and other nature conservation reserves containing wetlands over which the Department of Conservation and Natural Resources (CNR) has a management responsibility. It does not apply to wetlands in areas managed under the *National Parks Act 1975* (Vic.). The guideline also provides a basis for advice on grazing on private wetlands.

2. Background

Grazing by indigenous herbivores is a natural process in many wetland types. Particular grazing regimes appear to be necessary to maintain species and habitat diversity in some wetlands. Where grazing is removed from some vegetation communities, vegetation patterns will change.

Overgrazing appears universally to be damaging to wetland vegetation, soil and hydrological processes. Pugging of soil, promotion of weed and pasture species, low diversity of native plants and absence of slow growing or palatable species are some of the consequences of uncontrolled stock grazing. Some wetland types, such as alpine bogs and tidal marshes, apparently cannot tolerate livestock grazing (Costin 1958, Ranwell 1961, Arnold 1977, Reimold *et al.* 1975, van Rees & Hutson 1983).

In Australia formerly grazed herbaceous wetland vegetation tends to become woody or dominated by one or a few species of herbaceous plants when grazing is discontinued. In some wetlands, it may be appropriate to use livestock grazing as a means of managing vegetation structure or species composition. In other wetlands, livestock grazing will be inappropriate.

The value of free-range grazing to reduce fuel loads for fire management purposes is not proven (Burrows 1981, CFL 1988). The intensity of grazing required to reduce fuel loads is not compatible with the maintenance of nature conservation values.

3. Basis

This document is based on the role of CNR with respect to the protection of natural features. In recognition of the sensitivity of wetland environments and the general incompatibility of grazing in wetlands, this document seeks to limit grazing to appropriate applications only.

4. Guidelines

4.1 The Area Functional Manager is responsible for ensuring that grazing is only permitted in wetlands under his/her control where it is:

- required to manage indigenous biological values;
- a specific Land Conservation Council (LCC) recommendation;

- specified in an approved Wetland Management Plan (see Section 5.1).

4.2 Free-range grazing will not be used as a fuel reduction technique for fire protection purposes.

4.3 Where grazing in wetlands is not consistent with Section 4.1, it must be phased out.

4.4 All breeds of domestic horses, sheep and cattle are considered livestock for the purposes of this guideline. Pigs and goats are destructive foragers and must not be permitted in wetlands.

4.5 CNR Areas will set appropriate licence conditions and specify grazing regimes that meet management objectives.

4.6 Grazing licences or agistment permits issued for wetlands will be issued for a maximum period of twelve months. Renewal of licences will be subject to an assessment of the impacts of grazing on the wetland. Fees charged for the grazing of livestock will be determined in accordance with Crown Lands and Assets Division procedures.

4.7 Where fencing is required to manage or exclude livestock, fencing will be consistent with the *Fences Act 1968* (Vic.).

4.8 Where fencing required to manage livestock denies livestock traditional access to water, stock owners may be granted access to water. The CNR Area will liaise with the Rural Water Corporation as appropriate.

4.9 The use of supplementary feeds will be prohibited.

5. Procedures

5.1 Determining if grazing is appropriate

5.1.1 Grazing will be permitted in High Value and other wetlands where the LCC has made a specific recommendation to allow grazing in a wetland.

5.1.2 Where there is no specific LCC recommendation or the LCC recommendation is to allow grazing at the discretion of the land manager, the relevant Functional and Area Manager will only permit grazing in High Value or other wetlands as specified in an approved Wetland Management Plan.

5.1.3 Where no plan has been prepared grazing will not be permitted in High Value wetlands. The relevant Functional and Area Manager may permit grazing in wetlands not designated High Value where :

- the biological values of the reserve will not be threatened;
- it is required to manage indigenous plant communities or species e.g. to control a palatable species threatening to dominate an area;
- it is required to reduce vegetative cover to maintain open water or structural diversity;
- it is required to control palatable exotic plant species;
- strip-grazing a fenced area will maintain a firebreak (see *11.4PL Fire management in wetlands).*

5.2 Determining the grazing regime

5.2.1 Grazing regimes will be determined, for those wetlands where grazing is permitted, in accordance with Appendix 9d.

5.2.2 The stocking rate should be less than the carrying capacity and should be determined to minimise the impacts on palatable/grazing sensitive indigenous species rather than the perceived 'feed' value of the whole of the vegetation of the area being grazed (see Appendix 9d).

5.3 Grazing licences/permits

5.3.1 Grazing licences or agistment permits are required in order to graze stock on Crown land (see Section 7). Where short-term grazing is required, an agistment permit is appropriate. Grazing licences are appropriate annual licences. Fees and charges will conform with Crown Lands and Assets Division procedures. If grazing is for management purposes fees and charges may be appropriately reduced.

5.3.2 Grazing licences or agistment permits must specify:

- no supplementary feeding to be undertaken;
- the type of stock to be grazed (the livestock type will depend on the aims of management);
- the period to be grazed;
- the stocking rate (as number of head per hectare);
- under what conditions the licence or permit will be cancelled or suspended;
- other conditions as required by the CNR Area.

5.4 Licence/permit administration

5.4.1 All licences and permits for grazing must be issued in accordance with the relevant legislation (see Section 7) and in line with the relevant Departmental policies and guidelines. All licences and permits must be entered on the LIMS system.

5.4.2 CNR Areas should assess the impacts of grazing and review the grazing regime and licence conditions before renewing licences or permits (see Section 5.5). Grazing should be continued, modified or phased-out as appropriate.

5.5 Review of grazing

5.5.1 The Area Manager must ensure that grazing ceases in all High Value wetlands as soon as practicable after designation unless it is a specific recommendation of the LCC or a management requirement of an approved Wetland Management Plan.

5.5.2 The grazing status of other wetlands will be reviewed from time to time.

5.5.3 Where the CNR Area determines that grazing is not consistent with Section 5.1, licensees will be given appropriate notice of licence or permit cancellation, depending on the licence/permit conditions and the time required to resolve fencing or boundary issues. Where possible, the CNR Area will phase out grazing as soon as practicable from High Value wetlands and wetlands with rare or threatened species or species listed under the *Flora and Fauna Guarantee Act 1988* (Vic.).

5.6 Monitoring

Grazing management

5.6.1 An Agricultural Licence Field Assessment Form will be completed **annually prior** to licence/permit renewal and preferably at the end of March and

November each year. The results of inspections and completed forms will be placed on the appropriate CNR Area file.

5.6.2 The CNR Area should modify the grazing regime if grazing appears to be threatening the biological values of the reserve.

5.6.3 Area staff should inspect grazed wetlands regularly, as resources permit, to:

- check for and report the illegal presence of stock;
- ensure that stocking rates and other licence conditions are observed;
- monitor the amount of water withdrawn for stock where this is a permitted activity.

Impacts of grazing on biological values

5.6.4 The CNR Area will monitor grazing in wetlands and record the current and historic grazing regimes using a system such as the Resource Evaluation and Monitoring System (REAMS) (Cropper 1991).

5.6.5 The results of monitoring of grazing will be lodged with the CNR Area Wetlands Data System.

5.6.6 CNR Areas should, where possible and appropriate, establish grazing exclusion plots in grazed High Value wetlands and other grazed wetlands. The plots should be monitored regularly to determine the long-term effects of grazing and withdrawing grazing on vegetation, in particular:

- the appearance of new species (native and exotic);
- the disappearance of species (native and exotic);
- changes in the size or distribution of species populations (native and exotic);
- changes in species dominance;
- changes in vegetation structure.

5.7 Fencing

5.7.1 Where fenced boundaries are required for the purposes of managing or excluding grazing, CNR Areas should act in accordance with *10.5E Fencing boundaries of Crown land with private land* (in Estate Management Manual). As fencing is a sensitive issue, co-operation and mutual agreement with adjoining land owners are to be encouraged.

5.7.2 Where the current cadastral boundary is inappropriately placed, fencing may be facilitated by:

- land swap;
- land purchase;
- joint management agreements;
- a written agreement on the boundary alignment by the land owner and the Area Manager.

5.7.3 CNR Areas will use appropriate means to ensure that the boundaries of High Value wetlands are fenced as soon as practicable after designation.

5.7.4 Where wetland reserves are not grazed and have public land/road frontage, the CNR Area may consider removing fencing on the Crown/road frontage to save maintenance costs and to make illegal grazing difficult. This may not be appropriate on livestock droving routes.

5.8 Access to water

5.8.1 Where access to water is requested, the CNR Area may grant access for stock to the wetland or grant access to the water. For access to water for wetlands not fed by streams or other waterways, the CNR Area will issue an annual mill pump or pipeline licence for an appropriate fee (consult with the Crown Lands and Assets Division) For wetlands fed by a water supply system or wetlands which are a waterway managed by a water management authority, the CNR Area will liaise with the Rural Water Corporation to ensure that a 'Take and Use' water supply licence is issued with appropriate conditions.

5.8.2 The amount of water made available to the stock owner will be set at a level that protects the natural hydrological regime of the wetland. A meter or staff gauge may need to be installed to measure withdrawals.

5.8.3 The stock owner will be responsible for constructing the water supply system required to deliver the water to a suitable stock watering point. The Area Manager or nominee will set appropriate conditions for access.

6. Definitions

Carrying capacity. The number of livestock the grazed area is able to carry throughout the entire year. This is expressed as an average rate per grazed hectare i.e. DSE/ha.

Dry sheep equivalent (DSE). The amount of feed required for a 45 kg sheep not lactating or gaining weight. One dry cow is equal to 10 DSE.

Free-range grazing. The grazing of stock that is unrestricted over the total area available under a grazing licence or agistment permit.

High Value wetland. A wetland that has been accepted by the wetlands scientific committee areas meeting one or more of the high value criteria (see Wetlands Conservation Program, p. *17)*

Grazing regime. The elements of stock number per hectare (stocking rate), season of grazing and duration of grazing, each of which may be varied to arrive at a desired livestock management system.

Livestock/Stock. All breeds of cattle, sheep and horses are regarded as livestock for the purposes of this guideline. Pigs are not regarded as livestock.

Strip-grazing. The controlled grazing of stock in strategic locations to achieve a required effect, e.g. a high level of grazing and trampling of fine fuels to achieve a reduction in fire hazard.

7. Legislation

Land Act 1958 (Vic.)

- Sections 123 to 125, and 130 relate to administration of grazing leases.
- Section 133A relates to the granting and administration of agistment permits.
- Section 188 allows for the Crown to take action against owners of stock which strays onto vacant unreserved Crown land.

- Section 401 relates to the granting and administration of grazing licences on water frontages.
- Section 401(1) allows for depasturing of cattle and sheep only, and part (3) includes horses in the definition of cattle.

Forests Act *1958* (Vic.)

- Section 51(a), 52 and 58(5) relate to leases and licences for the grazing of cattle.
- Section 78(3) provides for the power to impound trespassing cattle.
- Section 88(1) specifies penalties for illegal grazing.

Fences Act *1968* (Vic.)

- Section 31 excludes the Crown from being liable to pay for any part of the cost of the construction or repair of any fence dividing Crown land from private land.

Wildlife Act *1975* (Vic.)

- Section 14(b)(i) states that the Secretary has responsibility for the management and control of wildlife reserves.
- Section 16(2)(a)&(e) relate to the granting of licences, authorisations and control of use.
- Section 17(1) relates to monies and fees collected from wildlife reserves.
- Section 19a(4) provides for the power to remove or impound trespassing stock.

Crown Land (Reserves) Act *1978* (Vic.)

- Section 15(1)(g)&(i) relate to permits to graze stock.
- Section 15(1)(h) provides for the power to impound stock.

Wrongs Act *1984* (Vic.)

- Places fault with the owner of stock should stock wander.

Flora and Fauna Guarantee Act *1988* (Vic.)

- Section 11(3) allows for potentially threatening processes to be listed.
- Section 19(1) allows for action statements for listed taxon or community or threatening process.

Water Act *1989* (Vic.)

- Section 51(1) states that a person may apply for a licence to take and use water from a waterway, where waterway includes a lake, lagoon, swamp or marsh and land regularly covered by flood waters.
- Section 51(3) states that a licence issued for Crown land may include authority to install and operate works on that land for the purpose of raising water to be taken and used.
- Sections 234 and 235 relate to water access with or without agreement by the landowner.

8. Cross references to other procedural documents

8.1 NPS Guidelines and Procedures Manual

2.4.1P	Clearing along boundaries by private land owners 05-20-0005-2
11.4PL	Fire management in wetlands 02-20-0726-2
11.5PL	Restoration of wetlands 02-20-0727-2

8.2 Other procedural documents

10.5E	Fencing boundaries of Crown land with private land 02-20-0650-1

Flora and Fauna Guarantee Policy and Procedure Manual 05-20-0139-1

9. References

Arnold, A. H. (1977) A review of the effects of grazing on natural ecosystems in Victoria. Dept. of Crown Lands and Survey, Melbourne.

Bonham, C. D. (1989) Measurements for terrestrial vegetation. Wiley, New York.

Breckwoldt, R. (1983) Wildlife in the home paddock. Angus and Robertson, Australia.

Burrows, N. D. (1981) Fire hazard reduction by cattle grazing in *Pinus radiata* D. Don plantations in the Blackwood Valley. *Forests Dept of Western Australia. Res. Pap.* 67.

Corrick, A. H. & Norman, F. I. (1980) Wetlands of Victoria I. Wetlands and waterbirds of the Snowy River and Gippsland Lakes catchment. *Proc. R. Soc. Vict.* 91:1-15.

Costin, A. B. (1958) The grazing factor and the maintenance of catchment values in the Australian Alps. *Aust. Div. Plant Ind. Technical Paper No. 10,* CSIRO, Canberra.

Cropper, S. (1991) The Resource Evaluation and Monitoring System. NPPL, DCE, Victoria.

CFL (1988) Forest Management Guidelines for Wildlife Conservation. Department of Conservation, Forests and Lands, East Melbourne.

Myers, K. & Poole, W. E. (1963) A study of the biology of the wild rabbit *Oryctolagus cuniculus* (L) in confined populations: IV. The effects of rabbit grazing on sown pasture. *Journal of Ecology,* 51: 435-451.

Paijmans, K., Galloway, R. W., Faith, D. P., Fleming, P. M., Haantjens, H. A., Heyligers, P. C., Kalma, J. D. & Lofffler, E. (1985) Aspects of Australian wetlands. *Division of Water and Land Resources Technical Paper No. 44,* CSIRO, Canberra.

Ranwell, D. S. (1961) Spartina salt marshes in south-east England. I. The effects of sheep grazing at the upper limits of Spartina marsh in Bridgewater Bay. *J. Ecol.* 49: 325-340.

Reimold, Linthurst, R.A. & Wolf, P.A. (1975) Effects of grazing on a salt marsh. *Biol. Conserv.* 8:105-125.

Short, J. (1985) The functional response of kangaroos, sheep and rabbits in an arid grazing system. *Journal of Applied Ecology,* 22: 435-447.

van Rees, H. & Hutson, G. D. (1983) The behaviour of free-ranging cattle on the alpine range in Australia. *J. Range Management,* 39: 392-395.

Appendix 9d Determining Grazing Regimes for Wetlands

1. Background

The effects of grazing a wetland will vary with:

- the timing of grazing (season and duration);
- the type of stock (cattle readily enter water to graze emergent plants, sheep are less likely to enter water, cannot graze in deep water and are less likely to be grazed on wet sites due to the dangers of foot rot);
- the stocking rate;
- the plant community and in some instances the species being grazed;
- the presence and numbers of native and exotic grazers;
- the prevailing climatic conditions.

Grazing impacts will be greatest:

- at high stocking rates;
- when plants are in reproductive phase;
- where long•term grazing exhausts the ability of plants to maintain health and vigour;
- where and when wildlife breed on the ground or in low herbaceous vegetation;
- where grazing opens up the herbaceous sward and allows the ingress of weed species or reduces its value to wildlife;
- where the soil is wet;
- where the community is under some additional stress such as during droughts or following fire.

The variables over which managers have most control are timing of grazing and stocking rate. The grazing regime for a wetland can be derived by considering these and should be designed to minimise the inputs listed above.

2. Timing

Grazing can be timed to minimise damage to particular vegetation communities and disturbance to wildlife, although few if any regimes are likely to protect all grazing sensitive species. The requirements of grazing sensitive, rare or threatened species should determine how and when their habitats are grazed, if at all. The duration of grazing should be determined with this in mind and the following is a broad guide to the timing of grazing:

All wetlands—avoid soil pugging and reduction in water quality by grazing only over the driest part of the year, from mid-summer to autumn i.e when herbaceous annuals and perennials are exposed by low water or summer drought and are least likely to be damaged by grazers;

Wet grasslands—avoid grazing in winter and spring, or where wet soil conditions persist;

Herbs and herbaceous communities—avoid grazing from July to December;

Herbaceous wetland communities—avoid grazing from July to December;

Woody species and communities—once the growing point of regenerating plants is beyond the reach of stock, graze only when forage levels are sufficient to avoid damage to the conductive tissue of the plants;

Wildlife—avoid grazing when wetlands carry significant numbers or species of breeding wildlife e.g. areas of rank grasslands, reed and rush beds, beaches during the period August to December.

3. *Stocking rate*

Stocking rates in wetlands and on other areas of unimproved pasture are frequently based on historical precedents. At best it is the number of stock that can be maintained outside the growing season.

It is not practical to try to determine stocking rates for wetlands. Grazing regimes can be derived from similar vegetation communities with the same management needs in the same climatic zones.

Stocking rates are determined from an understanding of the responses of the vegetation being grazed to differing grazing regimes under varying climatic conditions. Permanent exclusion plots serve as a valuable reference that enables the impacts of grazing to be assessed.

Populations of indigenous and pest grazers should be considered when determining stocking rates. The estimated number of rabbits for one dry sheep equivalent (DSE) ranges from 7 to 16 (Myers & Poole 1963; Breckwoldt 1983; Short 1985). Kilogram for kilogram, kangaroos are reported to eat the same amount as sheep (Breckwoldt 1983; Short 1985).

9.5 FIRE MANAGEMENT IN WETLANDS

CNR No: **02-20-0726-2**
Originator: **HULL, Foletta**
Distribution: **NPS GUIDELINES AND PROCEDURES MANUAL**

1. Application

This guideline applies to all wetlands on public land managed by the Department of Conservation and Natural Resources (CNR). In particular, it applies to:

- LCC (wetland) wildlife and lake reserves—the whole reserve area;
- high value wetlands—the whole wetland area and a 100 metre buffer;
- other wetlands on other Crown land categories—the whole wetland area and a 20 metre buffer.

This guideline should be applied when:

- formulating aspects of CNR Area Fire Protection Plans related to wetlands;
- undertaking fire management activities in wetlands;
- using fire for ecological management.

It also provides a basis for providing advice to managers of wetlands on private land.

2. Background

Fire is a frequent and regular event in a wide range of wetland types. Fire can:

- stimulate primary productivity;
- enhance wildlife habitat;
- destroy peat beds;
- change the vegetation composition;
- reduce the organic surface layer;
- expose roots and rhizomes;
- increase sedimentation;
- increase water temperature by reducing the vegetation cover.

Wetlands need to be protected from the adverse effects of fire, taking into account public safety, and recognising that in some instances fire is part of the ecology of wetlands and may be used in managing natural wetland habitats.

3. Basis

This guideline is based on CNR's responsibility to protect the indigenous species and communities, functions and landscape character of wetlands. It should be read in conjunction with CNR Area Fire Protection Plans, the CNR guidelines for preparing those plans and the Code of Fire Practice. Where wetlands are associated with parks and reserves, 15.8R Fire management in parks and reserves should also be referred to.

Although wetlands are found on most public land categories managed by CNR, the bulk are in parks and conservation reserves managed by the National Parks Service (NPS).

4. Guidelines

4.1 General management

4.1.1 CNR recognises that not all wetlands are equally at risk from fire, and will apply the following guidelines and procedures according to the:

- relative fire hazard and risk present;
- threat posed to fire-sensitive assets, features and adjoining properties;
- conservation status of the wetland;
- likely environmental costs and benefits;
- degree and level of public use and access.

4.1.2 CNR will, wherever possible, ensure that fire management activities and techniques minimise changes to surface drainage, disturbance to soil and ground litter and the removal of vegetative cover.

4.1.3 CNR will monitor and record the effects of fires on wetlands and record all burns and fires in wetlands.

4.2 Fire protection

4.2.1 The protection of significant fire-sensitive wetland features or assets will be resolved during the preparation/review of CNR Area Fire Protection Plans.

4.2.2 Fire protection operations should minimise the threats or damage to significant wetland features and assets and give due regard to public safety.

4.2.3 CNR will consider significant fire sensitive features and assets and wetlands that receive a high level of public use when planning for fire protection or allocating resources.

4.2.4 Fuel reduction burning is generally inappropriate in wetland vegetation. Where burning is carried out, it must be in accordance with CNR Fire Protection Instruction No. 2 *Conduct of Departmental Burning Operations*

4.2.5 Strip-grazing by stock to heavily graze or trample a fenced strip has some merit as a fuel reduction technique. The practicalities of this method in conservation reserves are unknown. CNR will only permit free-range grazing of domestic stock in wetlands where it complies with *11.3LW Livestock grazing in wetlands.*

4.2.6 The CNR Area Fire Protection Plan will address the issue of firebreaks in wetlands in accordance with this guideline.

4.2.7 The use of fire in linear burning patterns for fuel reduction may be acceptable for establishing a fire break adjacent to wetland vegetation and should observe the same conditions established for other firebreaks. Where such use is independent of a vehicle track, burning locations should be rotated to increase the time between burns on any one site. Burn frequency will depend on the vegetation type and the objectives of management.

4.3 Fire suppression

4.3.1 CNR will give priority to significant fire sensitive features and assets and wetlands that receive a high level of public use when allocating resources for fire suppression activities.

4.3.2 Fire suppression operations should minimise the threats or damage to significant features and assets and give due regard to public safety. Those techniques with the least environmental impact should be used, such as:

- hand-cleared fire breaks;
- water applied from specially equipped 4WD vehicles, tankers, tractors and boats;
- aerial water bombardments from helicopters and fixed-wing aircraft;
- back-burning;
- non-nutrient based foam retardants and surfactants.

4.3.3 CNR will ensure that any works that modify wetlands to gain access to water for fire suppression will be carried out in an environmentally sensitive manner.

4.3.4 CNR will rehabilitate wetlands where fire suppression activities adversely effect the hydrological, biological, landscape or recreational values.

4.4 Ecological use of fire

4.4.1 The use of fire for ecological purposes in wetlands should be adequately researched to minimise adverse effects to any fire-sensitive communities or rare or significant flora or fauna. Where burning is carried out, it must be in accordance with CNR's Fire Protection Instruction No. 2 *Conduct of Departmental Burning Operations* and *15.8R Fire management in parks and reserves.*

4.4.2 Ecological burns should be located so as to maximise fire protection benefits.

4.5 Rehabilitation

4.5.1 Where fire suppression activities change natural drainage patterns or damage/destroy indigenous vegetation in a wetland, CNR will ensure that the disturbed areas are rehabilitated as near as possible to their pre-fire condition (refer to *11.5PL Restoration of wetlands).*

4.5.2 CNR will make the control of pest plants and animals a priority action in high value wetlands recovering from fire.

5. Procedures

5.1 Planning

5.1.1 The Area Functional Manager will ensure that wetland management is considered when developing and reviewing the CNR Area Fire Protection Plan, particularly in relation to:

- fire protection and fire suppression strategies;
- managing fire risk associated with the recreational and commercial use of wetlands;
- the application of fire for ecological purposes.

5.1.2 The Area Fire Management Officer will ensure that the CNR Area Fire Protection Plan and the three year fire protection works program consider the fire management requirements of wetlands. The preferred fire management status of wetlands is 'Priority Four burning' or 'Planned not to be burned'.

5.1.3 The Area Functional Manager will provide the Area Fire Management Officer with a map showing the location of high value and fire sensitive wetlands and wetland features. The Area Fire Management Officer will lodge this map with the other Assets Maps and incorporate the information onto the base maps used to prepare fire history and three year operations maps.

5.1.4 The Area Functional Manager will ensure that new facilities are located to minimise the risks of unplanned fire and take advantage of natural fire resistant features and established fire protection works.

5.2 Public access

5.2.1 The Area Functional Manager will ensure that all recreational use of fire shall be in accordance with the relevant legislation and that the proper use of fire is encouraged by appropriate signage (refer to *Signs Manual).*

5.2.2 The Area Functional Manager will ensure that public access, where it is provided, maximises public safety in the event of fire.

5.2.3 The Area Functional Manager will ensure that licence or permit conditions for commercial operations in or adjacent to wetlands minimise fire risks.

5.3 Management access (water supply and fire management)

5.3.1 The Area Functional Manager will ensure that where access to a wetland for water supply is a strategic need of an approved CNR Area Fire Protection Plan, water will be obtained in an environmentally sensitive manner. That is:

- vehicle access to the water's edge will be minimised (water should be provided to tankers away from sensitive vegetation via pumps and hose lines wherever possible);
- existing tracks and hardstand areas (e.g. picnic areas, car parks, wayside stops) are used for access and fill areas wherever available.

5.3.2 The Area Functional Manager will ensure that where access is recognised as a fire management need in the CNR Area Fire Protection Plan a strategic track network will be established or maintained. Tracks will:

- be located at least 20 metres from the edge of the upper limit of seasonal wetting (except in floodplain vegetation);
- avoid biologically sensitive areas;
- be appropriately marked to avoid disturbance to other areas;
- have a maximum surface width of 6 metres.

5.4 Fire protection

5.4.1 The Area Fire Management Officer will ensure that, where required, firebreaks:

- are located at least 20 metres above the upper limit of seasonal wetting (except in floodplain vegetation);
- maximise the strategic benefits provided by existing public roads, management tracks and fire resistant natural features;
- avoid non-flammable low herbaceous vegetation types;
- are located, wherever practical, in areas that are already degraded or of a lower conservation significance than the area being protected;

- are established using techniques that minimise soil disturbance wherever possible. Methods which retain ground cover but reduce fuel levels, such as slashing, frittering and in some instances burning are preferred. High-impact techniques for establishing firebreaks should generally be avoided.

5.4.2 The Area Functional Manager, in consultation with the Area Fire Management Officer, will ensure that slashing and frittering are timed to achieve maximum fuel modification to reduce flammability.

5.4.3 The Area Functional Manager will ensure that where strip grazing by stock is used to reduce fuel that:

- the area being grazed is of lower conservation significance than the area being protected;
- the first 20 metres at least above the upper limit of seasonal wetting is avoided (except in floodplain vegetation);
- the width of the grazed area is appropriate to the fire risk;
- it is economic compared with other fuel reduction techniques;
- electric fencing, where used, does not pose a fire risk.

5.5 Fire suppression

5.5.1 The Area Fire Management Officer will brief senior management of volunteer fire fighting organisations on the need to maximise the protection of wetlands from fire suppression activities. A copy of this guideline should be provided for information.

5.6 Fire management for ecological purposes

5.6.1 The Area Functional Manager may authorise the application of fire for ecological purposes.

5.7 Rehabilitation

5.7.1 The Area Functional Manager will suspend grazing in wetlands recovering from fire, consistent with 11.3LW *Livestock grazing in wetlands.*

5.7.2 The Area Functional Manager will ensure that rehabilitation work is consistent with *11.6PL Managing water in wetlands* and *11.5PL Restoration of wetlands.*

5.8 Monitoring

5.8.1 The Area Functional Manager will will ensure that details of all fires are recorded in the *Fire Information Resources and Equipment System* (FIRES) and Area wetlands databases.

5.8.2 CNR Areas will undertake monitoring projects, using the appropriate method, following burns or fires in wetlands, particularly in high value wetlands. 'Monitoring the ecological effects of fire' (CFL 1987) is a useful reference for this work.

5.8.3 The National Parks and Reserves Branch can provide technical advice to CNR Areas undertaking monitoring projects.

5.8.4 Where strip-grazing is used as a fuel reduction technique, the methods and results should be recorded. The details of stock type, stocking rate, strip width, fencing arrangements, pre and post-grazing fuel loads and total cost should be recorded for each vegetation type grazed.

6. Definitions

Fire protection—those activities undertaken before a fire breaks out to lower the risk of fire and aid fire suppression.

Fire suppression—those activities undertaken to control and extinguish a fire.

Significant fire-sensitive features and assets—features such as bird nesting sites /colonies in woody vegetation, relics of Aboriginal occupation or early European settlement, or facilities such as board walks or bird hides etc. which are regarded as significant assets and sensitive to damage by fire or fire suppression activities.

Strip-grazing—the controlled grazing of livestock over a linear area, usually on a land tenure boundary, usually with the aid of temporary fencing on at least one side.

Tritter—a series of rotating heavy metal hammers pulled behind a tractor, used to break down and compact low, woody and herbaceous vegetation.

7. Legislation

The Wildlife Act 1975 (Vic.) provides the legislative basis for the management of State Wildlife Reserves and Nature Reserves.

Section 30 (e) of the Country Fire Authority Act 1958 (Vic.) allows the Chief Officer or any person exercising those powers to access any water for fire fighting purposes. Section 40 of the Act covers the declaration of days of total fire ban and exclusions from the restrictions on lighting fires on such days for the purpose of preparing meals.

Section 20(b) of the Forests Act 1958 (Vic.) requires the Secretary to provide for the prevention and suppression of fires within fire protected areas. Section 22 states that CNR is responsible for preparing and putting into operation plans for the protection of State forest from damage by fire. Section 62(2) details the responsibility of CNR in regards to carrying out fire prevention works in State forest and national parks and on all protected public land in agreement with the persons or bodies having management control of those areas. Section 63 details the restrictions placed on the lighting of fires in certain areas. Section 64(1) prohibits the use of fire when acute fire danger exists. Section 64(1)(b) allows for leases and permits to be suspended under acute fire conditions. Section 99A provides the ability to set times for which regulations apply and allows for certain exemptions to be granted.

Regulations 7, 8 and 9 of the Fire Protection Regulations 1992 relate to the lighting, kindling or maintaining a fire. Regulations 10, 11 and 12 relate to camp-fires and barbecues. Regulation 26 determines that fires must be extinguished.

Sections 17(2)(b) and 18(2)(b) of the National Parks Act 1975 (Vic.) state that the Director shall ensure that sufficient measures are taken to protect each area managed under the Act from injury by fire. Section 23 allows for permanent protection works to be carried out.

Regulation 7(i)(h) of the Park Regulations 1992 relates to the setting aside of areas in parks for fireplaces or fires of a particular type or areas where fires are prohibited. Regulation 7(2) relates to the prohibition or restriction of access for purposes of protection and preservation or managing and controlling parks. Regulation 7(3) details the Director's responsibilities with respect to the erection of signs and the determination of times for which access prohibition or restriction applies. Regulation 10 outlines special conditions relating to the lighting and maintaining of fires in parks.

Section 20 of the Crown Land (Reserves) Act 1987 (Vic.) relates to fire prevention works on land reserved under Section 4 that is not protected public land.

8. Cross references to other procedural documents

8.1 NPS guidelines and procedures

4.2.2P	Camp-fires in parks 05-20-0143-1
11.3LW	Livestock grazing in wetlands 05-20-0324-1
11.5PL	Restoration of wetlands 02-20-0727-2
11.6PL	Managing water in wetlands 02-20-0728-1
15.8R	Fire management in parks and reserves 05-20-0090-2

8.2 Fire Protection Instructions

Fire Suppression (Instruction No. 1) 05-20-0120-1

Conduct of Departmental Burning Operations (Instruction No. 2) 01-20-0108-1

Fire Protection Issues on Private Land (Instruction No. 14) 05-02-0122-1

8.3 Other procedural documents

Area Fire Protection Plans

CNR (1995) Code of practice for fire management on public land.

CNR (1995) Fire management on public land in Victoria: background document.

9. References

Burrows, N.D. (1981) Fire hazard reduction by grazing cattle in Pinus radiata D. Don plantations in the Blackwood Valley. Paper No. 67, Forests Department of Western Australia.

Cropper, S. (1991) The Resource Evaluation Monitoring System. NPPL, Department of Conservation and Environment.

CFL (1987) Monitoring the ecological effects of fire. Fire Research Liaison Group, Fire Protection Branch, Department of Conservation Forests and Lands, Victoria.

Government of Victoria (1988) Wetlands Conservation Program for Victoria. Department of Conservation and Environment, Victoria.

9.6 RESTORATION OF WETLANDS

CNR No: **02-20-0727-2**
Originator: **HULL, FOLETTA**
Distribution: **NPS GUIDELINES AND PROCEDURES MANUAL**

1. Application

This guideline applies to all natural wetlands managed by the Department of Conservation and Natural Resources (CNR) which are in need of restoration. It provides a guide for vegetation establishment in artificial wetlands, and a basis for advice on the restoration of wetlands on land managed by other authorities.

2. Basis

Restoration of wetland habitats is a complex exercise involving the management of land use, hydrology and vegetation. Its success is largely dependant on the mitigation of activities and processes that adversely affect natural wetland processes and biological communities.

Although wetlands are found on most public land tenures managed by CNR, the bulk are in parks and conservation reserves managed by the National Parks Service (NPS).

3. Guidelines

3.1 General considerations

3.1.1 Where possible, wetlands will be restored by removing or mitigating degrading influences and/or management activities (e.g. controlling pests, removing grazing, protecting from fire, and maintaining an appropriate water regime), and by restoring drainage patterns.

3.1.2 Management of water and potentially degrading influences (e.g. grazing, pest plant control) will be in accordance with *11.6PL Water management in wetlands, 11.4PL Fire management in wetlands* and *11.3LW Livestock grazing in wetlands* and with other CNR policies and guidelines (see Section 8).

3.1.3 Livestock grazing is generally inappropriate in wetlands being restored.

3.2 Revegetation

3.2.1 The response of existing vegetation to the removal or mitigation of degrading influences and the restoration of original drainage patterns should be determined before active revegetation is considered.

3.2.2 Active revegetation of wetlands will only be undertaken where the current condition of the vegetation is inadequate to meet management objectives and recolonisation is slow or unlikely to occur without intervention.

3.2.3 Only species originally found in the wetland (indigenous) will be used for revegetation except where it is appropriate to establish refugia for threatened or rare species which are or were present locally but not on the site.

3.2.4 Propagules and plant transplants used in restoration works will, wherever possible, be obtained from within the catchment of the wetland being revegetated.

3.3 Pest plant and animal management

3.3.1 An ongoing pest plant and animal control program should be included in the restoration program.

3.3.2 Physical disturbance within 20 metres of the highwater mark of a wetland should be avoided to minimise weed invasion of the upper zone of seasonal wetting.

3.3.3 The benefits of control methods that cause physical disturbance to soils and vegetation must exceed the environmental costs.

3.3.4 Only registered herbicides may be used to control pest plants in wetlands containing water. Phosphate and nitrogen-based herbicides must be used with care to avoid nutrient enrichment of sites and must not be used in communities in naturally low-nutrient situations (e.g. peat bogs).

3.3.5 CNR Areas will ensure that the spread of weeds or pathogens within and between wetlands is minimised by cleaning soil and plant material from clothing, equipment and vehicles before leaving contaminated sites.

3.3.6 Sites infested with noxious weeds, soil borne pathogens or weeds known to be of concern in wetland environments will only be used as sources of soil-bearing transplants or propagules to revegetate wetlands where those weeds or pathogens are already present in the wetland and no 'clean' alternative exists.

3.3.7 Species such as *Typha orientalis, T. domingensis* and *Phragmites australis* should not be regarded as pest plants on sites where they are indigenous. There may, however, be a need to control populations to prevent dominance. Control methods should be appropriate to the species and the management objectives of the site.

3.4 Soil stabilisation

3.4.1 Where filling drained or dry wetlands is likely to produce unnaturally turbid water or may result in erosion of the shoreline, investigations should be undertaken to determine whether the soil/shoreline should be stabilised before filling. Hydroseeding using indigenous or sterile, annual exotic grasses, hydromulching or 'enviromat' products are useful stabilising techniques.

3.5 Monitoring

3.5.1 CNR Areas should regularly monitor:

- the response of wetlands and, in particular, vegetation to changes in degrading influences and management activities;
- the results of active revegetation and/or soil stabilisation.

NB Advice is available from National Parks and Reserves Branch, NPS.

4. Procedures

4.1 Planning

4.1.1 The Area Functional Manager will ensure that wetlands requiring restoration are restored to a condition that approaches, as near as is practicable, their pre-European settlement condition.

4.1.2 Management activities for restoration of wetlands must be specified in approved area or species management plans. Where no plans have been developed, restoration programs must be approved by the Area Functional Manager in consultation with the Area Flora, Fauna and Fisheries Manager.

4.1.3 The Area Functional Manager will ensure that management plans and restoration programs:

- give priority for restoration to high value wetlands;
- detail the aims of the project;
- consider the type of wetland (including vegetation communities) to be restored;
- consider the type and degree of degradation;
- recommend techniques that are appropriate to the problem;
- include details of budget and time constraints of the project;
- detail a method for monitoring the success or failure of the project.

4.2 Active revegetation

4.2.1 The Area Functional Manager may decide to actively revegetate a wetland after giving due consideration to the response of the vegetation after the removal or mitigation of degrading influences and the restoration of original drainage patterns (this may require monitoring over several years) and the likely future condition of present vegetation.

4.2.2 The Area Functional Manager will determine the existing and likely future condition of vegetation by considering:

- the reproductive/colonisation potential of the species present on the site, as indicated by vigour and age;
- the current species richness of the community as compared to less degraded wetlands of the same physical type;
- the presence of soil-stored propagules;
- the proximity of the wetland to sources of propagules and the ease by which these propagules may be transported unaided to the wetland (e.g. by water flows or wildlife movements);
- the pest plant and animal species present.

4.3 Active revegetation techniques

4.3.1 The Area Functional Manager will actively revegetate a wetland using one or a number of the following techniques: transplanting, direct seeding or planting nursery propagated seeds or cuttings.

NB1 Not all techniques are suitable for all species. More detailed information on techniques and suitable species is available from the *Manual of Wetlands Management Techniques* (CNR—ANCA in prep.).

NB2 At least two years planning may be required to obtain nursery grown plant stock for planting out at the appropriate time. A few commercial nurseries have expertise in the propagation of wetland species (refer to *Manual of Wetlands Management Techniques* (CNR—ANCA in prep.) for more information).