Wetlands
Guidelines for protection and management

Department of Conservation and Environment Bulletin No. 79

Department of
CONSERVATION and ENVIRONMENT

your ref:
our ref: 185/77 JA:RE
enquiries:

WETLANDS : GUIDELINES FOR PROTECTION AND MANAGEMENT
DCE BULLETIN NO. 79.

In 1977 the Department of Conservation and Environment issued a publication entitled Guidelines to the Conservation and Management of Wetlands in Western Australia. The guidelines were intended to improve general understanding of wetlands so that an informed public would recognise their importance in our complex web of life.

Following the wide circulation of this publication a need has been seen to revise it and to improve its presentation. This new Bulletin is based on wider local knowledge and an extensive review of Australian and overseas publications on wetland management.

The Bulletin provides background information, advice and recommendations supported by published information. The recommendations are advisory and indicate the best possible options rather than requirements under existing legislation.

The Amendment of the Environmental Protection Act since the Bulletin went to press has necessitated a minor change to the text. Page 27 under the heading EXCAVATION, should now read :

Mining

i An appraisal of the potential environmental impact of a development proposal should be carried out prior to the granting of a mining tenement in a wetland area. The proponent of a development proposal should refer it to the Environmental Protection Authority (EPA) through the Department of Conservation and Environment (DCE) in the form of a Notice of Intent (NoI). The details of a Notice of Intent are laid down in the Department's Bulletin No. 38. The purpose of a NoI is to allow the EPA to make a preliminary assessment of the likely environmental impact of a proposal, and to establish what further action is necessary. The NoI should contain sufficient information to enable the EPA to determine whether a detailed environmental

1 Mount Street, Perth, W.A. 6000 tel. 322 2477

assessment is necessary, or whether it can recommend, through the Minister for Conservation and the Environment to the Minister charged with administering the Mining Act, that the proposal can go ahead as proposed or under specific conditions.

The incorporation of environmental considerations during the preliminary feasibility studies of development proposals, will in most cases avoid costly environmental problems during the operation and post operation phases of the project.

I commend Bulletin 79 to your attention and I would be pleased to receive your comments about it in the light of your experience.

C.F. Porter
DIRECTOR.

13 March, 1981.

GUIDELINES FOR THE CONSERVATION AND MANAGEMENT OF WETLANDS IN WESTERN AUSTRALIA

DEPARTMENT OF CONSERVATION
AND ENVIRONMENT, WESTERN AUSTRALIA

BULLETIN No. 79
FEBRUARY 1980

"The world's wetlands lie forlornly in the middle of the unfortunate, unnecessary but so far unresolved conflict between productivity economic and productivity ecologic." – R. Allen 1975(1)

CONTENTS

PART 1: INTRODUCTION

THE DEFINITION OF WETLANDS

There are many definitions of "wetlands", some of which are specific to certain geographical areas. In Western Australia wetlands have been defined by the Wetlands Advisory Committee as:

"Areas of seasonally, intermittently or permanently waterlogged soils or inundated land, whether natural or otherwise, fresh or saline, e.g., waterlogged soils, ponds, billabongs, lakes, swamps, tidal flats, estuaries, rivers and their tributaries." (2)

THE VALUE OF WETLANDS

Wetlands are valuable assets in Western Australia for the following reasons:

Water resources. In a country where water is scarce and groundwater is used for domestic water supply the connection between wetlands and groundwater must be realised. Around Perth the wetlands are essentially points where the water table comes above the ground level. Therefore, any filling with municipal refuse can bring about serious leachate contamination of groundwater reserves.

The vegetation and peat surrounds of wetlands also act, to a certain extent, as filters for surface runoff that enters groundwater through wetlands. Thus the preservation of wetland surrounds can assist in the removal of runoff pollutants such as nitrogen and phosphorus (from fertilisers), pesticides, heavy metals (from roads and cars).

Drainage. All wetlands act as natural drainage basins for the surrounding area and can easily survive periodic inundation. If wetlands are filled and areas which once acted as buffer zones for surge runoff, e.g. river flats, are removed then flooding can occur causing costly damage to urban development. The drainage or filling of wetlands can also interrupt the underground flow of water to the sea. This flow, if stopped, can allow salt water intrusion into groundwater.

Natural habitats. Wetlands support a wide range of aquatic and terrestrial plants and animals whose survival and well-being are directly related to that of the wetlands. One hundred and four species of birds alone are dependent on Australia's wetland habitats. (3)

Because of their biological diversity and high productivity wetlands also have economic value. For example, estuaries function as the nursery and feeding grounds for a very large percentage of fish taken by commercial and amateur fishermen on our coasts (4). Streams and lakes are also used for recreation fishing (5). Wetlands also play a part in breeding and sustaining other species of benefit to man, for example ibis, which eat insects, and ducks which provide the basis of a game industry (6, 7).

Study and education. The biological diversity of wetlands provides useful areas for both school and tertiary students to learn the principles of biology and ecology. The relationships between wetlands and groundwater, food production industry, are all areas which have been and will continue to be of great interest to researchers (8).

Recreation. An increasingly important function of wetlands, especially in urbanised areas, is that of recreation. Activities such as boating, swimming, fishing, water skiing, crabbing, prawning and even new sports like hang-gliding require areas of open water. While other more passive pursuits such as picnicking, bush walking, photography and barbecues do not necessarily demand waterside venues, they are greatly enhanced by them. Wetlands can also provide much-valued scenic and landscape features. The Swan and Canning Rivers, in particular, are a scenic and recreational focus for the people of Perth (9). Associated with this role is the economic value of such areas in attracting tourists, who are drawn both to the scenery and the wildlife, particularly the concentrations of birds usually associated with wetlands (6, 7).

Aesthetics. Within the philosophy of suburban design there has been a move away from the regimented man-made environment that characterised suburban design of the 1950's and early 60's. Increasingly, suburban designers are attempting to blend with nature. Therefore, the preservation of water bodies produces scenery that is more pleasing to view and provides surroundings which are more 'natural' in their appearance.

Wetlands are thus an integral part of our Western Australian way of life comparable in importance with the Coastal Zone itself (10). They are resources worthy of respect and their exclusion from any short or long term resource planning in Western Australia's developing economy would lead to impoverishment of the Western Australian life style.

WETLANDS–THE DWINDLING RESOURCE

Historically, the attitude towards wetlands has been one of exploitation–for transportation, water supply, drainage, waste disposal, mining, agriculture and so on. They are filled in to provide sites for housing estates or industry and are frequently used as rubbish dumps. The largest losses have perhaps resulted from drainage of land for its conversion to agricultural uses, especially on fertile soils. Various forms of recreation also exert pressure on wetland ecosystems, although not usually in such an obtrusive manner.

The impact of exploitation on Western Australia's wetland resources is graphically emphasized by a 1974 estimate that 200,000 hectares of land representing 75% of the wetlands on the Swan Coastal Plain had been filled or drained. Of the remaining 65,000 hectares of wetlands, about 40% had potential to be reclaimed using existing techniques (3). Since this survey, an increasing population and a "development"-oriented economy have brought greater potential for reclamation, for pollution of wetlands and for the use of the water supplies (both surface and underground) which sustain them. Salination resulting from extensive clearing presents yet another threat to many wetland areas in the wheatbelt.

Through lack of consideration of wetland management in conjunction with development, the community is losing scenic and recreational amenities, and the flora and fauna dependent on wetlands are also threatened by exploitation of their habitats. Many native species of animals have either perished or been reduced to low numbers as a result of our disregard for any wetland-users other than man (3). For instance, in Western Australia, the known breeding habitats of the Short-Necked turtle are only two small swamps. If these swamps are removed in all likelihood this species will vanish.

AUSTRALIA'S INTERNATIONAL RESPONSIBILITY

The loss of wetlands is not restricted to Western Australia. It is a world-wide problem (11, 12, 13, 14, 15, 16). In 1974 Australia signed the "Ramsar Convention," which required contracting parties to designate wetlands (within their territory) of international significance in terms of ecology, botany, zoology, limnology, or hydrology. Moreover, under the terms of an agreement with Japan, Australia is obliged to protect migratory birds and their habitats. This includes over twenty species of birds that depend on wetlands for their survival. Examples are certain species of egret, dotterel, plover, sandpiper and other migratory waders. Australia was one of the first countries to have designated a wetland for conservation when the Convention came into force on 21 December, 1975 (1, 17, 18). The wetland designated under the terms of this Convention was the Cobourg Peninsula on the Northern Territory coastline.

Australia, therefore, has an international responsibility to conserve and manage wetlands, as well as to protect them as an asset for its present and future generations.

SAVING OUR WETLANDS

Clearly, environmental management is an urgent priority if the developing social, economic, recreational and conservation demands being made on our wetlands are to be met in a productive and sustainable way.

One important method of achieving this is through a greater public understanding of wetlands and their value. An example of this is the inclusion of environmental considerations in the earliest stages of engineering, economic and other feasibility studies for a development project, so that land-use development planning includes measures to preserve and, where possible, improve wetlands.

THE PURPOSE OF THE BOOKLET

The purpose of this booklet, therefore, is to:

i serve as an input into the education of the public. In this regard, Section 2 places particular emphasis on the factors which cause wetland degradation.

ii provide guidelines for planners, developers, local authorities and land-owners as to the desirable approach to land-use development to ensure protection of surviving wetlands. This is dealt with in Section 3 in which it is stressed that wetland preservation is dependent upon protecting both the quantity and quality of the water. This section also attempts to delineate some measures for integrating wetland conservation and management into the planning of development proposals, e.g. for rural and urban subdivision, mining, sanitary landfill, and agriculture.

PART 2:

THE FACTORS CAUSING DEGRADATION AND DESTRUCTION OF WETLANDS

INTRODUCTION

Many of the major threats to our wetland resources result from human activities. Such activities can affect the wetland feature either directly e.g. the reclamation of a swamp, or indirectly e.g. the contamination of a swamp by pollutants leached from a rubbish tip remote from the wetland.

The greatest threats to wetlands in Western Australia (not necessarily in this order of importance) are:

drainage and filling
excavation
pollution
eutrophication
erosion
water level changes
salination
aesthetic disruption
aquatic weeds
insect pest control

DRAINAGE AND FILLING

Agriculture. The wetlands of the Swan Coastal Plain and south west of the State have been subjected to agricultural pressure since white settlement.

Agricultural uses of wetlands are diverse, including intensive cropping of swamps for growing vegetables, fodder crops, perennial pastures, annual and volunteer pastures (19). In addition, water bodies within wetlands provide a source of reclaimable land which may be drained for agricultural use. While it has been estimated that the net increase in value of reclaimable land is $100 per hectare per year (19), this cost analysis excludes any Government financed works which may be necessary to enable the land to be drained, or to alleviate subsequent flooding problems elsewhere.

Approximately 16,000 hectares of wetlands have been reclaimed since 1955 on the Swan Coastal Plain alone, probably mainly for agriculture (19, 20). Despite a diminishing supply of wetlands, agriculture is likely to continue reclamation by drainage for some time to come at the rate of about 150 hectares per year (19).

Agricultural land releases of large packages of vacant Crown land in other parts of the State are still proceeding, including in arid and semi-arid zones. This must be viewed as a threat to any wetlands within these areas, unless their protection is taken into account during the release and subsequent agricultural development of the land. Apart from direct destruction through reclamation, the most significant effects are related to the clearing of land of natural vegetation, including:

i the possible effects of increased siltation and salination of major potable water resources;

ii the possible detrimental effects of increased siltation, salination and generally lowered quality of ground and surface waters flowing from the subject land into wetlands in National Parks, nature reserves and other farms;

iii the destruction of flora and fauna habitats (21).

Urban and industrial development. Wetlands which occur in or near towns and cities often come under great demand for drainage and filling for a number of reasons. Most often it may be considered that in the short term the land could be put to more profitable use, by providing sites for housing estates, recreation, industry, tourism, or foreshore roads and freeways.

Swamps, tidal flats and river flood plains are also considered, by some, to be "unsightly," or they may be the source of a mosquito or midge problem for nearby residential developments (see Section 3, page 39). The process of "beautification" of such wetlands involves many operations including filling of swamps and reed-beds (often by rubbish disposal), dredging of seagrass beds and mud flats, construction of steep-walled banks often lined by retaining walls, and replacement of natural foreshore vegetation with grassed and landscaped areas for recreation.

Removal of wetland vegetation reduces the evapotranspiration from the region and hence produces a rise in the water table.

Drainage and flood-mitigation. Filling of flood plains and natural drainage depressions in conjunction with urbanization of the catchment can cause flooding (22). In a fully urbanized catchment, runoff is up to six times greater than the natural discharge (22). Flood peaks are higher and recharge of ground water is reduced (23). Stormwater drains convey this runoff (usually to streams and rivers) much more rapidly than natural seepage; flood flows along the creek can thus be increased by up to 300%, causing the stream to leave its banks (22). This in turn leads to the necessity for stormwater basins, and the "improvement" of rivers and streams by straightening, clearing and desnagging, and bank stabilization (often by concrete lining or barrel draining) (22, 24). Other measures include the use of levee banks, floodgates, drainage channels, floodways, dams and off-river storages (24). This filling of flood plains and 'improvement' of rivers effectively removes the source of water that would periodically inundate the wetland. Thus wetlands are destroyed.

These measures are also used in agricultural drainage schemes and to maintain navigable waterways (25).

Sanitary landfill. Landfill is the most common form of disposal of refuse, accounting for 80 to 90% of the world's rubbish (26). Commonly used sites include low-lying land, valleys, and areas involving the reclamation of land from water (26). This has been the case in Perth, where many completed and existing sites involve filling of swamps and river foreshores including the Swan and Canning Rivers, Bibra Lake, Lake Pinjar (27). In 1973, 43 sites were assessed to cater for sanitary landfill waste disposal during the following 20 years; the environmental acceptability of 34 of these became doubtful because of their location in wetlands or water supply areas. Although many of these sites are now no longer under consideration, the generation of solid waste in Perth is expected to increase dramatically over the next decade, creating continuing demand for land for disposal. This dilemma could be alleviated

to a great extent if technological development and economic change stimulated widescale waste recycling and resource recovery. Until this happens, sanitary landfill will remain the major method of disposal. The need to locate new disposal sites in environmentally acceptable areas is therefore urgent (28).

Effects of destruction of wetlands. Already over 75% of the wetlands in the Swan Coastal Plain have been lost through drainage or filling (3, 20). In the U.S.A. by contrast, the U.S. Soil Conservation Service has estimated that about 36% of that Nation's wetlands have been drained (12). These figures make it clear that, although, each land reclamation scheme, argued in terms of its own objectives, may look relatively insignificant against the total wetlands area, when the effect of many schemes is aggregated the overall potential impact on the ecology of the area is enormous.

Where drainage or filling does not encompass an entire wetland, but is confined for instance to river flood plains or the margins of lakes or estuaries, total destruction may not occur but the undesirable consequences are many, including:

- i effects on the food chain for example small animals which live in shallow water may be killed, thereby removing the food source for fish, which in turn reduces the food for birds and man;
- ii destruction of wildlife habitat, including waterfowl breeding sites;
- iii disturbance of mud and sand, bringing sediments into suspension, lowering light penetration and hence photosynthesis, and causing deoxygenation;
- iv disruption of local hydrology or drainage patterns (associated with the tendency towards steeper banks, and decreased areas of shallow water and periodically inundated land);
- v general disturbance resulting from the increased access to, and use of, the wetland associated with foreshore reclamation (including noise and disruption of foreshore and shallows vegetation, e.g. by stock grazing and trampling, boat-launching and recreational use).

Drainage and flood mitigation works can lead to long-term changes in stream velocity, denuding beds and banks, and increasing silt-loadings and turbidity (5), with consequent loss of fauna habitats and aesthetic and recreational appeal. These effects are discussed in more detail in ref. 24 and 25.

EXCAVATION

Mining. Mining of wetlands for peat, clay, diatomaceous earth or mineral sands can alter the wetland's value as a wildlife habitat by:

- i altering water depth;
- ii creating turbidity;
- iii destroying reed beds and other habitats;
- iv disturbance due to noise, presence of machinery and human activity;
- v altering drainage patterns;
- vi the removal of seasonal fluctuations in the wetland water level reduces the number of habitats available to wildlife.

(Effects of mine waste disposal are dealt with under Pollution).

However, while landfill is permanently destructive, controlled mining may be potentially beneficial in the long term by creating areas of open water for wildlife and recreational use.

Dredging. Sediments in estuaries may contain a desired resource (such as sand, shellgrit, mineral sands), or they may accumulate, hindering navigation or causing flooding. Often the accelerated accumulation of sediments is the result of man's interference with the natural vegetation in the catchment, e.g. by forestry, agriculture, mining or urban development (4). Dredging in estuaries, whether for resource recovery (mining), removal of "soils," or cutting or maintaining navigation channels, is a common activity which has many adverse effects on the ecosystems (4). These can include effects on the physical and biological environments, and on the human community (29).

For example:

- i acceleration in natural processes of sediment erosion and deposition (29);
- ii changes in hydrology. Large-scale alteration of the floor of the estuary can affect natural flow patterns and circulation, and hence the salinity regime (4);
- iii generation of turbid conditions during dredging (29);
- iv direct destruction of plant and animal communities within the dredging site (4, 29).

As a result certain biological changes take place such as:

- i changes in the kinds, abundance and distribution of organisms, and hence the fishery, induced by hydrological changes (4);
- ii settlement of dissolved particulate matter throughout the estuary, and adverse effects on survival and behaviour of plant and animal species (29);
- iii reduced light penetration, with damaging effects on aquatic plants (29);
- iv depletion of dissolved oxygen content of the water (4, 29);
- v release of toxic substances which have accumulated in the sediments (4);
- vi reduced usage of the estuary by migratory fish species which are unable to tolerate turbid conditions (29);
- vii reduced usage of the estuary by birds (29);
- viii in the long-term diminished species diversity (29);
- ix effects on the human community related to aesthetic degradation, disturbance to fishery, and other factors (29).

Canal Estates. The practice of dredging artificial canals in estuarine or coastal wetlands and using the dredge spoils for landfill to create canal or key-type residential subdivisions may have many environmental effects, including:

- i damage to productive wetlands (4). This includes destruction of submerged and emergent wetland vegetation and marshland, and detrimental effects on the fauna (30);
- ii consequent conflict with amateur and commercial fisheries for fish, oysters and crustaceans (30);
- iii alienation of foreshores (4, 31);
- iv pollution (4). Inadequate provision for good water circulation often leads to lowering of water quality, particularly lowered oxygen and increased nutrient concentrations (30, 31);

v sedimentation of fine silts and organic materials which may require costly dredging (30, 31);

vi lowering of the water table, with possible consequent effects on vegetation beyond the boundaries of the actual building project (32);

vii restricted water bird habitats (32);

viii increased breeding of midges (31, 32);

ix flooding, particularly on major river mouths (31);

x increased turbidity (31).

POLLUTION

Sources and Pollutants. Pollutants may arise from point (or localised) sources, examples of which are industrial wastes, sewage effluents, effluents from agricultural processes, stormwater drains and livestock feedlots, mine wastes, discharges from watercraft and leachates from waste disposal sites. Non-point (diffuse) sources such as agricultural and urban water catchments are also sources of pollution. The pollutants may be discharged directly into a wetland or they may contaminate it indirectly following percolation into the groundwater (33), or entry into streams in the wetland's catchment area.

Table 1 lists the major sources of pollution and the range of pollutants that could emanate from them.

Effects of pollutants on wetlands. Pollutants may alter the nutrient levels (see Eutrophication), biochemical oxygen demand (BOD), amount of suspended solids, levels of organic compounds and trace elements, acidity or alkalinity (as indicated by pH measurements), salinity of the ground and surface water systems, or add new toxic substances foreign to the receiving water body, e.g. oily materials, radioactive substances, toxic chemicals. The effects of individual pollutants on aquatic ecosystems are described in ref. 43.

Thermal pollution, or alteration of the water temperature may also occur through the discharge of heated wastes or water from industrial processes (see Glossary).

Pollutants will directly or indirectly alter the physical, biological, thermal and other properties and hence the ecology of a wetland, although the degree of alteration will depend on the type and level of contamination and the original characteristics of the wetland. Such pollution is generally detrimental to the wetland, and often presents a hazard to man or his environment (26). For example: bacteria and viruses can cause diseases (e.g. cholera, typhoid fever and dysentery); the water may be rendered unsuitable for drinking, irrigation or recreational use; fishing may be affected (25).

The protection of groundwater from pollution is of particular concern as groundwater is extremely slow to cleanse itself of non-degradable pollutants (35). Once an aquifer has become contaminated it is exceedingly difficult and sometimes economically unfeasible to reclaim it (44). For example, at Montebello, California, seepage of 2-4D from a manufacturing plant persisted in groundwater for five years after the plant ceased operation (35).

EUTROPHICATION

Eutrophication is the nutrient enrichment of waters (see Glossary). In lakes, rivers, harbours and estuaries, the accumulation of nutrients is a natural process. These nutrients include carbon, hydrogen, oxygen, sulphur, potassium, calcium, magnesium, nitrogen and phosphorus. Algae thriving on these nutrients may be green, blue-green, red or brown in colour; in small numbers these plants are beneficial as they contribute to the oxygen balance in lakes and streams and also serve as food for fish (26).

In the presence of abundant nutrients rapid growth occurs resulting in an algal 'bloom'. This bloom can cause unsightly masses, depletion of oxygen and damage to aquatic life.

Over a long period of time all water bodies will undergo eutrophication. These natural processes of sediments enriching the water and slowly filling the water body, until it

TABLE 1: POLLUTION SOURCES AND POTENTIAL POLLUTANTS FROM SUCH SOURCES

SOURCE	POTENTIAL POLLUTANTS
HOUSEHOLD EFFLUENT –sewage and septic disposal systems	Disease-carrying organisms (e.g. bacteria and viruses). Nutrients, e.g. phosphorus and nitrogen (34). Other chemicals, e.g. fats, soaps, detergents, disinfectants, grease, pesticides, weedicides, chemical products from the degradation or organic matter.
WASTE DISPOSAL SITES –sanitary landfill and liquid waste disposal sites –industrial effluent pits and lagoons –mine waste disposal sites	Discharges and leachates, including nutrients; acids; alkalis; heavy metals and other toxic substances depending on the nature of the wastes, e.g. phenols, picric acid, metal ions such as iron manganese chromium, oils, tar residues, weed killer waste (35), fats, resins, lignins (36). Bacteria (particularly Salmonella) spread by scavenging birds, rodents and insects (37).
AGRICULTURAL RUN-OFF	Nutrients, e.g. fertilisers and animal wastes, which can increase nitrate levels in groundwater beyond acceptable levels. Sediments. Agricultural chemicals, e.g. pesticides, herbicides and weedicides (38, 39). Bacteria (37). For literature review, see ref 40.
RECREATION	Litter. Noise. Oil, e.g. from marine engines. Nutrients, e.g. fertilisers from lawns and gardens, watercraft discharges. Disease-carrying organisms, e.g. bacteria and viruses.
LAND CLEARANCE IN CATCHMENT AREAS	Salt. Sediments.
MINING –mine process or cooling water	Acid and alkaline wastes. Toxic substances, e.g. heavy metals and various chemicals. Sediments. Radioactive materials.
URBAN RUN-OFF	Disease-carrying organisms, e.g. bacteria and viruses. Fuel and oil, e.g. from vehicles. Litter. Sediments. Nutrients, e.g. fertilisers from lawns and gardens. Tyre rubber. Metals, e.g. lead, chromium, cadmium, asbestos, cement. Toxic chemicals especially in drains and outfalls. For detailed analysis, see ref 41, 42.
ACCIDENTAL INDUSTRIAL "SPILLS"	Oil; organic and inorganic chemicals as described under waste disposal sites.

becomes a peatbog and finally dry land, take many thousands of years.

Industrial, urban or agricultural development may accelerate the otherwise slow ageing process by increasing the amounts of nutrients entering the water, e.g. in industrial and domestic effluents, fertilizers, animal wastes and urban stormwater runoff (43, 45).

The effects of advanced eutrophication are:

i lush algae create problems of water colour, taste and odour, resulting in increased costs of water treatment (42, 26);

ii the excessive vegetation decomposes, causing odours and consuming oxygen vital to fish and other life (43, 46);

iii the water is less attractive for boating, fishing and swimming (26, 43);

iv changes in plant and animal life detract from natural beauty and reduce property values (43, 46);

v the more desirable types of fish may be eliminated (26, 43);

vi agricultural use of the water may be impaired, e.g. by reduced palatability; and the effects of bacterial and algal toxins (43);

vii irrigation canals may become clogged (26).

Phosphorus, carbon and nitrogen are cited as the major nutrients controlling aquatic plant growth (47); for most freshwater bodies, phosphorus appears to be the key "**limiting nutrient**," e.g. Peel Inlet, while marine waters, e.g. Cockburn Sound, tend to be nitrogen limited (45, 48).

When forests are converted to agricultural purposes the phosphorus exported per unit area of land surface increases greatly. Correspondingly if urban development occurs the phosphorus export again increases several-fold.

It is reasonable to assert, based on both overseas and Australian experience, that unless wetland catchment areas are managed to reduce the nutrient load entering the water body, eutrophication will cause a deterioration in wetland resources, particularly in urban and agricultural areas. Once a wetland has become eutrophic, it is extremely difficult to reverse the process, and even with good management recovery may take many years. Hence protection is most important and less expensive in the long term. (See Part 3). This is a case of prevention being better than cure.

SOIL EROSION

When rain falls on soil, its impact causes particles to be detached from the soil complex and to be transported by the water flow. This process may be accelerated by land clearing, e.g. for agriculture or to improve river views; and disturbance of landforms, e.g. by construction, mining, overgrazing, trail bikes and off-road vehicles, droughts, floods or high winds. Apart from soil loss, the resulting problems include sedimentation or clogging of streams and lakes, increased turbidity or cloudiness of the water, increased costs of water clarification in water treatment plants, and killing of photosynthetic underwater vegetation and of gill-breathing organisms such as fish and crustaceans, e.g. prawns, crayfish. The sediments may carry large amounts of material, including organic debris, litter and nutrients with the potential to pollute wetland waters.

The possibility of erosion, with resulting desertification of the land and siltation of potable water resources and wetlands, is considered by the EPA to be one of the major factors in the environmental assessment of the release of vacant Crown land for agriculture (21). Erosion of the banks of rivers and lakes usually results from the disturbance of foreshore vegetation by human activity, e.g. fires, digging for bait, clearing for recreational use and stock trampling and grazing. Watercraft, particularly high-speed power-boats, can also cause significant erosion of the banks of wetlands by the action of the wash on the shoreline. This erosion also contributes sediments, as well as producing ugly scouring of the banks. It may even lead to a change in the course of a stream, and in downstream effects.

WATER LEVEL CHANGES

Water supply—groundwater. Most wetlands of the south-west of Western Australia are surface expressions of the shallow groundwater table (49). Those few that are not are usually shallow clay pans fed from rainfall runoff and are ephemeral. The water level in the wetlands rises as a result of rain falling directly on to the water body or its surrounding catchment area, (surface run-off), and by groundwater inflow stimulated by rainfall recharge in the surrounding area. Normally the water table drops over the summer period but recovers again during winter and this process results in a seasonal fluctuation in the wetland water levels.

The unconfined groundwaters of the Swan Coastal Plain are being increasingly exploited to supplement Perth's water supply (50). Pumping of groundwater produces a "cone of depression" of the water table around each bore, and for a bore field the individual cones of depression may eventually meet and amplify the depression of the water table. If pumping continues over a long period of time at a rate that cannot be fully made up from rainfall replenishment, an overall regional lowering of the water table may result. This lowering is superimposed on the normal seasonal water level fluctuation. Such a lowering of the water table could lead to a reduction in the permanence, area, and depth of adjacent wetlands and, for some of the shallower lakes and swamps to the north and south of Perth which are close to productive bore fields, their actual disappearance.

A reduction in areas of open water would obviously mean the loss of waterfowl habitats as well as losses in aesthetic, recreational and other amenities, as well as the regenerative processes which take place in wetlands.

The lowering of the water table also changes plant communities, including those supported by the wetlands. As they are modified to suit the new drier hydrologic regime the fauna dependent on these plants will in turn be affected.

Waterfowl would be particularly susceptible to losses of already severely limited feeding and breeding sites, and summer drought refuges.

A more detailed consideration of the possible effects of groundwater drawdown on wetlands of the Northern Swan Coastal Plain is given in a report by the Western Australian Museum (51).

Water supply–surface water. The damming of rivers and lakes to impound water for domestic, agricultural and industrial use leads to an increase in depth and area of open stretches of water above the dam. In some cases, these areas can provide additional habitats for fish (5), wildfowl (52), and recreation (5, 52). Often, however, man-made bodies of water result in the loss of natural wetland areas and their replacement by deep, cold and less productive water storages.

The restriction of the flow of water downstream may have several effects, including:

i providing a barrier to the upstream movement of fish, and in many cases also downstream movement. This will interfere with the migratory movements of fish and their breeding, e.g. in Northern Australia dam construction has interfered with the spawning of Barramundi (*Lates calcarifer*) (5);

ii altered patterns of streamflow (5);

iii reduced incidence of downstream flooding (again with possible effects on fish and other fauna) (5).

(A more detailed consideration of these matters is presented in ref. 24, 53, 54).

Clearing. Land clearing for agriculture in the South-West or large scale urban developments tends to lead to an increase in surface run-off and a rise in the water table, with consequent increased areas and depths of open water (55) (see also Salination, below,).

Water level manipulation. Many lakes and swamps are subject to artificial manipulation of water levels by control of flows in natural or artificial drains leading to or from them.

Any marked fluctuations in the water level regime during the breeding cycle of the waterfowl can seriously affect their nesting habits. For example any sudden drop in the water level could cause the abortion of nesting activity, the nest to become accessible to predators or cause the adult birds to quit the nesting sites before their offspring are sufficiently developed to fend for themselves. Conversely, increased levels could flood active nesting sites, thereby limiting the availability of such sites or drowning newly-hatched offspring unable to vacate the nest.

The manipulation of water levels in wetlands that form important breeding habitats can therefore be an important factor in fulfilling the potential of a wetland. A local example is the Broadwater near Busselton in south-western Australia. Its value was increased as a summer refuge for Black Swans, and clutch losses were reduced, by a management programme involving water level controls as well as modification of existing nest mounds and provision of artificial nests (56).

Manipulation of gates in drains can also be used to control areas of open water for agricultural or recreational use, as well as a tool in wildlife management. For example, the water level in Big Swamp within the City of Bunbury is maintained using the back wash water from the town's drinking water filtration plant.

SALINATION

Many of Western Australia's wetlands in the dry inland areas are naturally saline. They are part of a drainage system once integrated and functional at some time in geologic history, but now ineffective and acting as an occasional sump in which the salts in solution in drainage water are concentrated by evaporation. Moreover, the soils of the landscape have concentrated salts in their profiles and these are easily dissolved and swept out into the drainage system if there is a marked alteration of the hydrologic balance, for instance through large scale clearing of the natural vegetation.

With clearing of the natural vegetation to make way for farms, perennial, deep-rooting plants are replaced by shallow-rooting annual crops and pastures, so that less water is transpired, i.e., drawn from the soil by the plants. As a consequence, the groundwater rises, and flushes out salts previously held in the soil profile. Thus, the saline areas increase in extent. Additionally, there is increased run-off and consequently flooding and water-logging of the lower-lying land. Concentration of the salts in flood waters by evaporation can lead to soil salination in these situations. The whole process results in increased quantities of salts being added to streams and rivers so that saline water moves downstream in the system, affecting rivers and associated wetlands which were formerly fresh. Notable examples of rivers affected in this way are the Swan, Avon, Blackwood (57), Murray River and Collie River (especially where it has been dammed to form the Wellington Dam) (58).

In intermediate rainfall areas (400 to 600 mm per annum) the same process may give rise to entirely new wetlands which initially may not be saline, e.g., the freshwater lakes and swamps of the sandplains both north of Meckering and near Brookton.

In the higher rainfall (>800 mm per annum) areas of the Darling range salination of wetlands is uncommon. However clearing of the natural forest increases the salinity of the water in streams as well as increasing runoff. The wetlands in the coastal plain into which these streams drain in turn may be seriously affected by increased salinity in the feeding streams.

"The most serious current hazard of man's activities lies in the build up of salinity of the groundwater to levels inimical to all beneficial uses to which such water is put" (35).

The possibility of salination of water resources and wetlands must therefore be considered a major factor in the environmental assessment of further large-scale clearing. The EPA has recognised this in its Statement on Vacant Crown Land Proposed for Agriculture (21).

AESTHETIC DISRUPTION

The visually degrading effects that human activity can have on wetland areas are widely evident throughout Western Australia, especially on the Swan Coastal Plain. So many wetlands have been exploited that only a limited number have their amenity or landscape value unimpaired.

Many activities, both uncontrolled and supervised, contribute towards degradation of the wetlands' scenic qualities.

Some examples of uncontrolled activities are:

- Littering and illegal dumping;
- Unchecked clearing, burning or grazing;
- Off-road vehicles (by disturbing vegetation and causing erosion);
- Power boating (by increasing turbidity through disturbing bottom sediments and by causing erosion of banks through their wash).

Additionally, official works and development programmes, such as sanitary landfill sites, construction of roadways, drainage undertakings (including river training) can impinge upon the beauty of the landscape.

AQUATIC WEEDS

Certain noxious weeds have the ability to propagate rapidly in wetland environments, to the extent that control is difficult before ecological damage to the wetland occurs. These weeds are usually aquatic macrophytes, of which 103 species (or groups of species) are listed as weeds of Australian inland waters (59). Twenty-nine of these species are deemed to cause serious problems (59). Those of greatest local concern are Salvinia (*Salvinia molesta*) and Water Hyacinth (*Eichhornia crassipes*). Other weeds, including *Hydrilla verticillata* and a complex of native plants are also found in drains, dams and irrigation systems in Western Australia (59).

Other alien plants which may also cause a weed problem in wetland environments are, Blackberries, Nut Grass, Watsonia, St. John's Wort and Soursob (60). The Bulrush (*Typha orientalis*), although a native plant, often replaces native reeds and rushes in disturbed situations. This species does provide suitable breeding and feeding habitat for several types of birds.

In Western Australia plants declared as aquatic weeds are:

Lagarosiphon, Elodea, Arrowhead, Alligator Weed, Leafy Elodea, Salvinia, Water Hyacinth, Water Lettuce.

Three factors contribute to problem growth of aquatic plants–plant factors, which include the plant's ability to grow fast, reproduce rapidly and survive adverse conditions; environmental factors, including the nature and continuity of the water supply and efficiency of dispersal agents; and the effects of man, including construction of lakes and canals, regulation of river systems, enrichment of water by agricultural and urban runoff, and introduction of alien plants (59).

These weeds disturb the wetland ecology, and affect man's uses of the water by interfering with irrigation systems and clogging drains, promoting certain diseases, causing aesthetic degradation of the environment, and interfering with boat movement (59, 61, 62).

Control measures for heavy infestations include:

i physical removal by hand or machine;

ii chemical control, e.g. blanket spraying with herbicides;

iii manipulation of environmental factors, e.g. water level;

iv biological control, use of herbivores;

v utilization of the weeds, e.g. as stock feeds.

Such control measures are often expensive, the cost of controlling water weeds in Australia being $1½ to $2 million annually (61), and can cause widespread ecological damage.

INSECT PEST CONTROL

Insects with aquatic larvae, which breed in wetland habitats, may be the source of a "nuisance" to surrounding human populations.

Locally, such insects fall into two groups, the mosquitoes (family **Culicidae**) and the non-biting midges (family **Chironomidae**) (63). The major causes of nuisance are the mosquito species *Aedes vigilax* and *Aedes camptorhynchus*, which breed on the samphire-heath tidal flats along the Swan, Canning, Serpentine, Murray and Collie Rivers and also in tidal flats associated with the Peel, Harvey and Leschenault estuaries (63). Other pests are the mosquitoes *Culex annulirostris*, *Aedes alboannulatus* and *Coquillettidia linealis* which may cause a periodic nuisance around the upper reaches of the Canning River and urban lakes, and non-biting midges around some urban lakes (63).

With increased urbanization, the problem of nuisance insects is expected to increase (63). Demands for the control of these pests may result in measures being taken which degrade wetlands. Such measures include:

i filling of wetland margins;

ii clearing of reed beds and other fringing vegetation;

iii use of chemicals (pesticides) which may have detrimental effects on other components of the ecosystem (63).

Such procedures for the management of local insect pests are generally the responsibility of Local Authorities (63). Several bulletins have been published dealing with current local mosquito control procedures (64, 65, 66, 67) and alternative methods of control procedures (64, 65, 66, 67) and alternative methods of control, including alternative chemicals, biological control and source reduction (63). Biological control measures are also reviewed in ref. 68.

PART 3:

GUIDELINES FOR THE PROTECTION OF WETLANDS

GENERAL COMMENTS

Having set out in previous sections the technical aspects of the value of wetlands and their modification by man, it now becomes possible to set out guidelines for the protection of wetlands. For convenience these will be dealt with in the sequence adopted in Section 2. The key to environmentally based planning is to integrate all facets of development with the natural environment, rather than to impose them upon it.

From this viewpoint wetland preservation required not only **protection of the wetland from physical disruption, such as by indiscriminate filling and drainage, but also protection of the quantity and quality of the water supply feeding it.**

By sound management, it is often possible to go further, and to improve or enhance the value of the wetlands for one or more beneficial uses.

The degree of protection and management required depends on the nature and intensity of the surrounding land-use, and also on the characteristics of the wetland itself.

Where the wetland has important attributes, such as:

- presence of rare or restricted flora or fauna
- use by high numbers of migratory or native birds
- outstanding scenic quality
- forming an integral link in a system of waterways above and below ground
- size which dominates a regional watershed

it should be **totally preserved.** No drainage, filling or other impact through development should be permitted.

Where the wetland has the potential to improve its contribution for wildlife, or for recreation, it should be **preserved** and **managed** towards fulfilling this potential. This may involve, for example, dredging to provide deeper areas of water for waterbirds or sport, provision of formal recreation areas on the banks or foreshore, and subsequent protection from detrimental sources of environmental impact such as pollution.

In order to achieve such preservation and management of wetlands, it is important that the value of any wetland be considered in the earliest stages of planning for any planned use of the wetland itself, or the surrounding area. In this way, whether the use involves an individual farmer planning to drain a portion of his property, or a company or government department planning a large-scale urban or other development, the areas most important for preservation can be assessed, and plans for their management can be incorporated into overall planning of the development. In most cases such environmentally-based planning will not only help to preserve what remains of our limited wetland areas for the future, but will also enhance the development itself through maintaining an attractive landscape feature. In the case of urban, tourist and smallholding developments in particular, this could be of economic advantage to the developer.

The following guidelines are put forward as examples of how the major problems outlined in Part 2 can be prevented, by taking wetlands into account in the planning stages of any development. Where possible, means of overcoming or managing existing problems are also outlined.

A further important aspect of wetland conservation is the reservation of wetland areas and their susbsequent management. This aspect is considered in a series of Bulletins on Wetlands of the Darling System (69, 70, 71, 72) and is not dealt with further here.

DRAINAGE AND FILLING

Agriculture.

i Consideration of release of Crown land for agricultural use should take account of the presence of wetlands of value (as defined under General Comments above).

ii Important wetlands within future agricultural land releases or within agricultural subdivisions should be protected, where possible, by reservation of valuable individual wetlands, important wetland systems, and river foreshores, and sufficient surrounding land to ensure the integrity of their water supply.

iii Reserves should include the open water area (in the case of lentic or still water wetlands), and a foreshore reserve encompassing at least the extent of the wetland vegetation, and preferably also a "buffer zone" (at least 20 to 30 metres) to minimize the effects of surrounding land use activities (2).

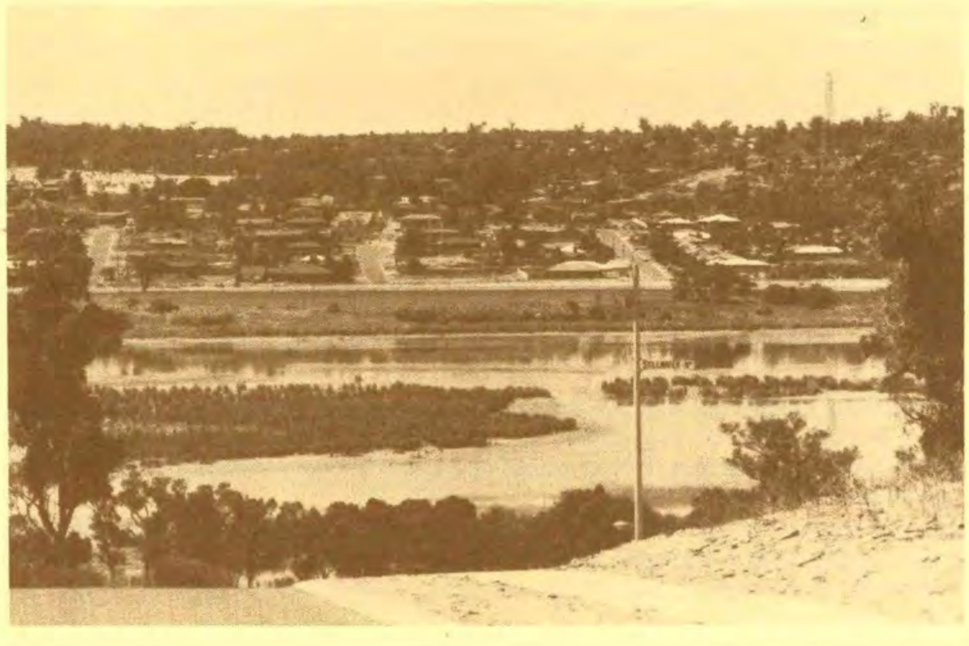
iv In view of the basic need for preservation of areas of permanent fresh water, such wetlands should be given high priority for preservation (2).

v While recognizing the added value to agriculture when wetlands are reclaimed, it is preferred that the decision to drain wetlands falling within agricultural holdings should take into account the criteria outlined in General Comments above.

iv If reclamation by drainage (or filling) must take place, then every endeavour should be made to ensure that the integrity of valuable wetlands and wildlife habitats is not threatened. This could be achieved by selective drainage, and a system of gates and/or bunding to provide water to the habitat at the desirable level (see Water Level Changes–Manipulation).

vii Protection of wildlife habitats within agricultural holdings may also require measures to prevent disruption by stock watering, grazing or trampling. This can be achieved by fencing of valuable wetlands, or of areas (such as waterfowl breeding sites) within them–limiting stock access to a few watering points as needed.

viii Where large drainage schemes or irrigation supply systems are proposed, measures should be taken to minimize damage to valuable wetland areas. An overall survey of the wetlands within the proposed scheme, such as that undertaken in the Kerang Region (73), can be a valuable input in the design of drainage schemes.



Urban development

i Residential or tourist developments which depend entirely on destructive filling of wetlands should be opposed.

ii Future town planning practice should prevent inappropriate developments (especially residential development) in flood-prone areas by rezoning (4). Public Works Department is preparing maps of most flood-prone areas in flood plains. These should be available from local authorities. Where they are unavailable reference should be made to the Public Works Department.

iii If there is no alternative to filling or draining part of a wetland area within a proposed development, care should be taken to ensure that the reclamation does not disrupt local drainage nor threaten valuable wildlife habitats, particularly of rare or endangered species of plants or animals.

iv Wetlands within areas proposed for urban development should be integrated into the development in order to achieve maximum beneficial use of their resources. For example, a wetland with value as a wildlife habitat could be preserved in public open space and utilised as an educational and passive recreation resource; a stream could provide informal open space, or linear parklands for hiking, cycling or riding, in conjunction with natural drainage and flood control; a natural drainage depression could be developed for stormwater disposal, perhaps in conjunction with deepening to provide permanent open water as a scenic and recreational attraction, as well as an improved area for waterbirds; a degraded watercourse could be revitalized as an adventure playground to complement the more usual recreational facilities. Retention of natural features can complement urban development (74).

v If a wetland is a known major mosquito-breeding site, then this should be taken into account before locating residential development in close proximity to it.

vi Where some filling is necessary, e.g. to improve the recreational potential, the following factors should be taken into account:

- **nature of fill**: only clean, non-polluting fill, such as clean sand, should be used (see Pollution). Any topsoil available, e.g. from road construction, should be used on banks and slopes.
- **slope**: for the following reasons, the gradient of the new bank or shore created by filling should be slight, preferably not more than 1 in 10:
  - to minimize erosion;
  - to maximize areas for the development of habitat diversity;
  - to allow fauna access to and from the water, e.g. tortoises must be able to climb out of the lakes in order to find breeding sites.
- **revegetation**: re-establishment of foreshore and marginal vegetation, e.g. reeds; may be necessary to prevent erosion and restore visual attraction to the area.

Some plants which are generally suited for planting around wetlands are listed below. Each wetland varies in the type of habitat and where possible the local vegetation should be allowed to recolonise the area surrounding the wetland (75).

i Emergent plants, for wetland edge

Baumea articulata
Scirpus validus
Typha orientalis
Polygonum minus
Juncus pallidus
J. polyanthemos
Melaleuca teretifolia
Lepidosperma longitudinale
Scirpus subfascicularis
Triglochin procera
Baumea juncea (brackish)
Juncus krausii (brackish)

ii Wetland edge–seasonally inundated

TS *Melaleuca rhaphiophylla*
TS *M. teretifolia*
H *Cenetella orbifolia*
ST *Eucalyptus rudis*
H *Polygonum minus*
H *Epilobium junceum*
H *Scirpus inundatus*
H *Patersonia umbrosa*
H *Euchilopsis linearis*
S *Eutaxia virgata*
S *Oxylobium linearifolum*
TS *Melaleuca uncinata*
S *Myoporum gracile*
TS *Agonis linearifolia*

Suitable for nutrient–poor soils
TS *M. preissiana*
TS *Viminaria juncea*
S *Melaleuca lateritia*
S *Aotus ericoides*
S *Pultenaea reticulata*
S *Astartea fascicularis*
S *Sphaerolobium vimineum*
H *Cyatochoetae avenacea*
TS *Banksia littoralis*
H *Deyeuxia quadriseta*
TS *Acacia saligna*
S *Leptospermum ellipticum*
TS *Kunzea vestita*
S *Hypocalymma angustifolia*
H *Carex appressa*
H *C. pseudocyperus*

The following plants are readily available from nurseries and are recommended (76).

T *Melaleuca cuticularis*
T *Melaleuca rhaphiophylla*
T *Melaleuca preissiana*
S *Melaleuca lateritia*
T *Eucalyptus camaldulensis*
T *Casuarina obesa*
S *Callistemon speciosus*
S *Beaufortia sparsa*
H *Lobelia quadrangularis*
H *Lippia nodiflora*

Key:
H = herb, grass or sedge
S = shrub $\leq$ 1 m
TS = shrub $>$ 1 m
ST = small tree
T = tree

Industrial development

i Industrial development relying entirely on reclamation of a wetland area should be avoided, unless the value to the community of the industry in question outweighs the biological, recreational, social and other values of the wetland.

ii If filling is absolutely necessary the natural values of all the alternative sites should be carefully considered, so that areas which are of outstanding value to wildlife or the community are preserved.

Sanitary landfill

i The use of wetlands, especially river foreshores, as sanitary landfill sites should be strictly avoided.

ii If there is absolutely no alternative to the use of a wetland, for instance, for social or economic reasons, a site should be selected where the wetland:
- has no outstanding value for other purposes (as defined on page 7);
- is not essential for local drainage;
- is not connected hydrologically, e.g. by a stream to other wetlands of higher biological or other value;
- is not situated in an area where groundwater is a source of domestic water supply;
- is not close to or used as a source of drinking water or water contact forms of recreation;
- is not close to any wetland of high value as a wildlife habitat to prevent the

spread of disease-causing bacteria to these wetlands, for example by birds such as seagulls.

iii The transmission of pollutants from sanitary landfill sites should be prevented (see waste disposal sites – domestic). Under no circumstances should dumping be allowed to proceed until:

- it is assured that the landfill will conform to the criteria of a sanitary landfill operation;
- any necessary leachate control works are established (77).

Drainage and flood mitigation

i While it is recognised that some flood mitigation works may be necessary for the protection of existing urban areas, the need for such schemes should not be used as a basis to justify the drainage of swamps which can then be used as agricultural land (4, 78).

ii Where flood control measures are necessary in urban areas, the channelizing of streams should be avoided. Channelized streams are frequently morphologically unstable, biologically unproductive, and aesthetically displeasing (79).

iii Measures to reduce flooding and control erosion and sedimentation problems in streams in urbanized areas should include utilization of the total catchment approach to river problems (e.g. reduction in rate of runoff) (80), promotion of bank stability by preserving vegetation and other bank stabilization techniques (79, 80) (see Erosion, page 35), and consideration of maintenance and enhancement of landscape, recreation and wildlife habitat values (80). The maintenance of wildlife values of streams and their frontages is dealt with in ref. 81 and 82.

EXCAVATION

Mining

i An appraisal of the potential environmental impact of a development proposal should be carried out prior to the granting of a mining tenement in a wetland area. The proponent of a development proposal should refer it to the Environmental Protection Authority (EPA) through the Department of Conservation and Environment (DCE) in the form of a Notice of Intent (NoI). The details of a Notice of Intent are laid down in the Department's Bulletin No. 38. The purpose of a NoI is to allow the DCE to make a preliminary assessment of the likely environmental impact of a proposal, and to establish what further action is necessary. The NoI should be sufficiently detailed to enable the Department to determine whether the proposal can go ahead as proposed or under specific conditions, or whether a detailed environmental assessment is necessary.

The incorporation of environmental considerations during the preliminary feasibility studies of development proposals, will in most cases avoid costly environmental problems during the operation and post operation phases of the project.

ii Wetlands of outstanding value, as defined on page 7, should not be mined until it can be demonstrated that the mining will be of long-term benefit to the wetland, and that the short-term effects of the mining activity can be managed to reduce any harmful impact on the wetland (see next recommendation).

iii Mining tenements on wetlands should include conditions to minimise disturbance during the mining activity, as well as to ensure appropriate rehabilitation when mining ceases. Such conditions could include:

- preventing water or material that, as a result of mining, contains substances that are damaging to the environment, being deposited within a specific distance from the boundary of the wetland;
- careful selection of sites for roads, structures or stockpiles;
- restrictions on the removal of vegetation, both below high water mark and on the shoreline;
- revegetation, if necessary.

iv Where the tenure of the land allows, excavation in non-wetland areas which have the potential to create artificial wetlands; should be rehabilitated after mining to maximise their value as wetland habitats for recreation and wildlife. The value of flooded gravel pits (83, 84), sand pits (83), worked out quarries (13), salt works (85) and clay pits (86), and artificial farm ponds (87) in wildlife conservation has been demonstrated. Recreation at intensities which would damage natural wetlands can also be channelled into these new areas (88).

v Measures to increase the value of mined or artificial wetlands to wildlife include revegetation (86, 89), control of water levels (85, 90), and land surface levels and slopes (90), and use of artificial islands (89). The requirements of birds in terms of wetland habitats are given in ref. 90 and 91, and more detailed management guidelines for the improvement of wetlands for wildlife in ref. 20 and 92.

Detailed design criteria for new ponds and lakes which can provide a focus for "lakeshore" developments are given in ref. 91.

Dredging

i A study of the hydraulic consequences of larger-scale dredging should precede any major dredging works (4).

ii Disposal of unwanted dredge "spoils," either in deeper parts of the estuary or in estuarine wetlands, should not be allowed. Preferably, planners should set aside non-tidal areas (not wetlands) for such operations (4).

iii Dredging programmes for navigation channels or training the mouth of a river or lagoon should always be preceded by an analysis of the estuary's sand budget to prevent costly and undesirable effects on channel stability, sand bars and beaches (4).

iv Dredging should only be undertaken after consideration of possible effects on the permeability of the lake bed, and hence water levels (see page 13).

Canal estates

i Dredging of artificial canals for residential development of estuarine wetlands should not be allowed without a thorough investigation of the environmental consequences (91).

ii Canal estates should not be permitted in areas where their development would lead to loss of valuable, productive wetlands, whose continued existence would be of greater long-term benefit to the community (in terms of recreation, aesthetic value, fisheries, etc.) than the subdivision.

iii Disruption of wetland and subtidal habitats should be avoided to the greatest extent possible by careful siting of canal developments and control of turbidity and sediment dispersion (see ref. 30).

iv The canal system should be designed to maintain water quality standards, by providing a flow-through system to provide adequate water exchange and maintaining nutrient input at low levels (30). Measures to achieve these goals are detailed in ref. 30, 31, and in this booklet under Eutrophication (page 34).

v Construction of groynes, breakwaters and other seabreaks should be approached with great caution (31).

POLLUTION

Non-point sources. The problem of control of non-point sources of pollution is immense, possibly equal to or greater than the problem caused by point sources (95). Diffuse sources of pollution are less easy to define and control, but measures to alleviate effects of non-point sources are vital if water quality is to be maintained, and the large monetary investment in control of municipal and industrial wastes not lost (95). The approach to non-point source pollution control is based on the concept of "stewardship of the land"–i.e., that man's activities in the use of the land should not destroy the land's productivity for future generations (95). Examples are: site practices to reduce unnecessary erosion (see page 35), managed use of agricultural chemicals (see page 32) and improved land development practices in connection with the siting of new subdivisions and developments.

Point sources

Household effluent. Control of point sources of pollution largely involves treatment of wastes (e.g. sewerage, industrial effluents) (see pages 15, 16) and/or their diversion from wetlands, as in the case of the strict licensing controls exerted over effluents discharged into the Swan River (9).

i High density (residential, tourist) developments should be deep-sewered and the wastes diverted away from wetland areas, to prevent pollution by nutrients, bacteria, viruses and chemicals.

ii Where deep sewerage is not practical because of economic or other factors, alternative means of sewage and sullage or "grey water" disposal should be designed, bearing in mind the need to protect the ground and surface water from contamination. This is particularly important when the groundwater is used as a domestic water supply, either via public or private bores, or where nearby wetlands are used for recreation or are valuable wildlife habitats. In this context the role of excess nutrient input in causing deterioration of water quality–and hence wetland degradation–is stressed.

iii Where on-site effluent disposal is the only alternative, the existence of a suitable site for septic tanks and leach drains (in relation to height above the water table, setback from water body, suitability of soils, etc.–see next two recommendations) on each lot should be verified before development occurs. While the effectiveness of septic effluent disposal systems would depend on local conditions (e.g. soil types, groundwater level, etc.,) it has been suggested by some overseas researchers that septic tanks are not satisfactory when the population is greater than 2.5 families per hectare (96). The Environmental Protection Authority of Victoria considers that "Provision of a full sewerage system, including tertiary treatment where dictated by water quality, should be a requirement in all urban subdivisions, i.e. lots of 0.4 hectare or less" and further that "In coastal areas with sandy soils nutrient enrichment of water bodies can occur from effluent discharges. These areas are generally not suitable for ground absorption of waste water discharges" (97).

iv Septic tanks and leach drains should be situated at least 2m above the expected highest level of the water table, to minimise the leaching or flushing of pollutants into the groundwater. **Septic tanks should never be located in areas of high water table** and must conform with public health regulations.

v **Septic tanks and leach drains should be set back at a sufficient distance from the wetland to minimise the transport of pollutants (in the soil or in the groundwater flow) to the water body.** Obviously it is extremely difficult to specify setbacks as the pollution potential depends on local conditions of soil types, topography, rainfall, water table level, and the density of the development. Clearly some guidelines in this regard would be desirable, and in fact Victoria has nominated setbacks for septic tanks from wetlands–100 metres from shallow, small and poorly flushed lakes, 50 metres from large, deep lakes and 25 metres from major, minor and intermittent streams. Leopold (ref. 23) states that "...no septic tank should be as close to a channel (stream) as 300 feet (100 m) if protection of the stream water quality is to be achieved." He goes on to say that "Even this minimum setback does not prevent the dissolved materials (nitrates, phosphates, chlorides) from enriching the stream water thus potentially encouraging the proliferation of algae and otherwise creating a biotic imbalance" (23). Chemicals (including nutrients) will travel far greater distances than bacteria, which are filtered out by soil particles. Therefore a setback which is sufficient to protect the water body from bacterial contamination is not necessarily sufficient to protect it from nutrient enrichment and consequent degradation.

Recent local studies of the movement of coliform bacteria (98) and phosphate and nitrogen (99) from septic tank effluent have shown that all of these contaminants may reach the groundwater.

Parker, ref 98, demonstrated that faecal bacteria can penetrate to depths of 0.8m, and therefore the depth of unsaturated soil necessary for the absorption of bacteria may exceed the commonly accepted minimum. This strongly supports previous recommendation that septic tanks should not be located in areas of high water table.

Ref. 99 estimates that about 400 tonnes of phosphorus in solution and about 2,200 tonnes of inorganic nitrogen are being discharged annually from septic tanks in the Perth area. They conclude that "...phosphate from septic tank systems constitutes an important potential source of phosphorus for urban lakes." Further, the inorganic nitrogen is largely oxidized to nitrate and "...moves readily to the groundwater and constitutes an important source for lakes. A more important aspect is the potential for increasing the nitrate concentration in drinking water. In the long-term, this could present a serious threat to public water supplies" (99).

These local studies emphasize the need for caution in the siting of septic tanks, both on public health and environmental grounds.

It is therefore recommended that Leopold's more conservative estimate of a **minimum setback of 100 metres from any wetland** be adopted, and that greater set-backs be considered in cases of high-density development, where the wetland is already showing symptoms of eutrophication.

vi Open areas between leach drains and the water body should be well-vegetated (by replanting if necessary), as plants draw nutrients from the groundwater system, thus reducing the levels of such pollutants reaching the wetland.

vii Alternative means of household effluent disposal are often environmentally preferable to septic tanks in locations adjacent to wetlands, and the use of alternatives should be seriously investigated, particularly in areas of high water table. These alternatives include:

- enclosed effluent storage tanks (periodically emptied by a waste disposal contractor);
- electric or gas powered incineration toilets;
- composting toilets, e.g. "Bioloos."

These alternatives are particularly useful for situations where use is intermittent, such as holiday cottages.

viii There should be adequate facilities for the disposal of liquid and solid wastes at all caravan parks and camping sites, including a common dump point, coupling installation and associated washing facilities, and separate and adequate provision for the disposal of hazardous wastes such as disposable nappies (100). Similarly, adequate facilities for the disposal of liquid and solid wastes from caravans and tourist buses should be provided at convenient intervals of approximately 500 km along main roads, to prevent caravaners from resorting to dumping wastes in unsatisfactory areas (100).

Waste disposal sites—domestic. Domestic waste disposal sites include sanitary landfills (rubble and household rubbish) and liquid waste sites, e.g. septic tank wastes. Household effluent has been dealt with in the previous section.

i The choice of site for waste disposal is of extreme importance (see sanitary landfill, page 26).

ii Pollution from waste disposal sites (whether wetland areas or not) arises by leaching of chemicals into groundwater, transport of chemicals and litter in surface runoff, and spread of bacteria from the site, e.g. by birds and other animals, (particularly sea gulls). The site should therefore be managed to prevent pollution, by:

- lining and bunding the site with clay or other suitable impermeable material to prevent leaching;
- bunding and manipulation of drainage to prevent runoff from the waste disposal area from entering natural drainage channels and hence wetlands;
- compacting (or pulverising) domestic wastes, to minimise surface area for leaching of chemicals;
- separate treatment of any noxious wastes;
- covering refuse at frequent intervals with sand to minimise leaching and avoid attracting sea gulls and other scavengers;

- if necessary, collection and secondary biological treatment and land disposal of leachates (101, 102);
- fencing the site to prevent access by animals, particularly dogs and cats, capable of spreading disease;
- continued monitoring of leachates after the completion of the landfill operation. Cracking of the fill cover due to shrinkage of the fill, poor maintenace of the finished fill during the first decade or two after its completion, and seismic disturbance, are among the ways avenues of entry of water may be opened with time (35).

iii Operating facilities for the land disposal of sewage effluent and sludge should be monitored, and the results considered in the design and operation of future installations to minimize pollution (103).

Waste disposal sites–industrial

i The choice of site is again important; the criteria listed for selection of sites for sanitary landfill (page 26) apply also to disposal of solid, non-toxic industrial wastes;

ii Ideally liquid industrial wastes should be treated, e.g. at a central treatment plant, before discharge, and diverted away from rivers, creeks and other wetland areas. This is particularly important if the wastes are high in nutrients or chemicals which are potential pollutants.

iii Groundwater should be protected from pollution by industrial wastes by strict control of discharges and measures to reduce the occurrence of accidental spills.

iv Where wastes are "ponded," whether or not in a wetland area, measures such as the following should be taken to prevent pollution of nearby ground and surface water:
- lining the bottom of the pond with clay or other suitable impermeable material to prevent leaching;
- bunding and manipulation of drainage to prevent run-off from the pond from entering natural drainage channels and hence wetlands.

v The wastes should be prevented from becoming a hazard to wildlife, e.g. waterfowl, which may be attracted to areas which appear to be open water. It is acknowledged that complete fencing and netting is to date the only proven reliable (albeit expensive) method. Further research into alternative methods, such as light reflectors, is to be encouraged.

Waste disposal sites–mining. Careful environmental assessment prior to detailed planning of mining projects results in the most effective control of the environmentally detrimental aspects of mining waste.

i An effective waste management programme for operating mines could include the following measures:
- the construction of suitably lined dams for waste water storage;
- in open-cut mining, the return of tailings to the mined-out areas, where, following consolidation and contouring they can be topsoiled and revegetated;
- the selection of appropriate impervious substrata in conjunction with surface drainage characteristics for the construction of tailings dams;
- the design of waste dams should incorporate storage capacity to accommodate peak rainfall and to reduce the driving force in embankment slip;
- the selection of stockpile sites away from the main natural drainage direction.

ii Hazards from wastes from abandoned mines should be reduced, for example, by:
- minimising the flow of mine water into natural drainage by channel and dam lining;
- reshaping of waste dumps;
- covering of the reshaped dumps with layers of clay, rock and soil;
- revegetation of the area;
- possible reprocessing if market values changed to make this viable. Further improvement in water quality may require the removal of contaminated stream and lake sediments and chemical treatment of all residual mine water.

Due consideration should be given to the type of mine wastes to be disposed. Those containing toxic impurities require different management and disposal techniques to those wastes which are free of such toxic constituents.

Agriculture–Point Sources. A wide range of enterprises is involved and includes animal feedlots, battery poultry sheds and processing factories, e.g. dairy product processing, wool scouring, hide tanning and the slaughter of farm animals. The contribution to pollution of wetlands and associated groundwater systems varies with the process involved, the quantity of waste generated, the factory or feedlot location, and whether the wastes are subjected to treatment.

i Point sources of pollution should be discouraged in areas of high water table, or high potential runoff. They should be sited on flat or gently undulating land, away from creeks, streams or other wetlands.

ii The nutrient output from these sources should be reduced, for example by:
- preventing water from outside feedlots from flowing through, e.g. by pipes, levees, dykes, roofing, evaporation ponds for runoff;
- collection of feedlot runoff in retention ponds of settling basins before disposal;
- treatment of wastes, e.g. biological oxidation in ponds;
- re-use, where possible, of the accumulated waste liquids and solids, e.g. by irrigation of wastes to recycle both water and fertilizer (not near wetlands).

Agriculture–Non-Point Sources. In controlling pollution of wetlands by agricultural runoff, the aim is to reduce the amount of nutrients (in the form of fertilizers and animal wastes), pesticides, weedicides, herbicides, and sediments reaching the water body.

i Sedimentation of wetlands by soil particles carried in agricultural runoff should be controlled in accordance with the methods outlined under Soil Erosion (page 35).

ii The widespread use of commercial fertilizers makes it necessary to modify agricultural practices to reduce nutrient enrichment and pollution of surface waters, for example by:
- careful determination of the amount and type of fertilizer required, in the light of nutrients already available in the soil, crop up-take and climate;
- split application of fertilizer, or use of slow-release nitrogen fertilizer, in soils of high permeability to reduce loss through leaching;
- maintenance of organic content of soil, e.g. by ploughing in cereal straw;
- limiting over-irrigation;
- avoiding applying fertilizer to slopes subject to rapid runoff;
- recycling animal manures and composting farm wastes (104);
- maintenance of a well-vegetated non-fertilized "buffer zone" along creeks and around the foreshore of swamps and lakes, to remove some of the nutrients from the run-off water;
- limiting stock numbers and stock access to wetland foreshores should be controlled.

iv The ecological effects of insecticides and herbicides on aquatic systems are still poorly documented. There is increasing evidence to justify the concern that ecological changes do occur, particularly from their indiscriminate use. In this regard it is worthy of note that the U.K. Pesticide Safety Precautions Scheme has only approved eight weed control chemicals for use in or near water.

These are:

2-4-D (amine salt), maleic hydrazide and dalapon (with or without paraquat) for bankside vegetation control, and chorthiamid, dichlokenil, diquat, paraquat, terbutryne and dalapon for aquatic vegetation.

Recent studies (105), however, have concluded that most herbicides will cause declines of both fauna and flora over a short period of time. The long-term effects are more difficult to assess.

For recommendations on nuisance insect and aquatic weed control, see Insect Pest Control (page 39) and Aquatic Weeds (page 38), respectively.

Recreation. The forms of recreation compatible with the type of wetland, and its other, or alternative, beneficial uses, should be carefully considered.

i If the wetland is of high value, particularly as a wildlife habitat, it merits protection from the impact of harmful activities. In this case recreational activity in and around the wetland should be restricted to passive, low-impact forms which are compatible with the maintenance of high scenic value and a "sanctuary" for wildlife. Activity centres such as walking trails, "hides" for wildlife observation, photography and scientific study, may be acceptable. In some areas, for example waterfowl nesting sites, all human activity should be excluded. This is usually possible simply by providing access paths to other areas, rather than by direct exclusion.

ii If it is established that the most beneficial use of all or part of a wetland is recreation, perhaps in conjunction with other uses, e.g. professional or amateur fishing; steps should be taken to reduce the pollution and other impact caused by recreational activity, for example by:
- the control of litter, by public education and the supply of ample strategically placed bins;
- the segregation, where possible, of sports or activities such as power boats which generate noise and other forms of disturbance from other more passive forms of activity. Highly active sports and recreational pursuits should be located in areas where the noise will cause least disturbance to wildlife and other people;
- provision of disposal facilities for toilet wastes from boats, house-boats in particular, to prevent discharge to water body.
- formal development of foreshore areas, e.g. as playing fields or parkland, should be maintained with minimum use of fertilizer and irrigation water which would add to the nutrient load of the wetland. One way of achieving this is to irrigate the foreshore with the lake (or river) water.

Land clearance–see Agriculture: Non-point sources of pollution, Soil Erosion, and Salination. (See pages 32, 35, 37).

Mining–see Waste Disposal Site–Mining and Soil Erosion. (See pages 31, 35).

Urban runoff (stormwater)

i The pollution potential of urban stormwater runoff should be reduced, for example by:
- controlling the source of pollutants, e.g. animal excreta, illegal dumping, litter, construction work, fertilizer and pesticide application, accumulation of rubbish and debris (42, 106);
- peak flow reduction – i.e. reduction in the overall volume and velocity of runoff, by minimizing infiltration of groundwater into the stormwater drainage system, by constructing porous pavements to reduce surface runoff, or the use of in-system storage, detention basins, or natural depressions to temporarily store excess peak flows (42).

ii Treatment of stormwater by screening to remove large debris, the use of detention basins, tanks or ponds, for settling or flotation (with or without chemical treatment), biological treatment such as trickling filters, or "activated sludge"' or by disinfection, usually in conjunction with screening, settling, or biological treatment (42, 106).

iii Diversion of stormwater runoff away from wetlands, particularly those of high natural value, is recommended. This could be achieved by discharge of stormwater to self-contained settling ponds, drainage sumps, storage reservoirs, etc., perhaps even to create "artificial wetlands" (106, 107).

EUTROPHICATION

Many of the recommendations under Pollution deal with ways of **reducing the nutrient input to wetlands.** This is regarded as the primary management step to reduce the acceleration of eutrophication.

For many water bodies, control of available phosphorus from external sources is the key (43, 47). In the past, eutrophication control measures have been largely directed towards control of phosphorus from point sources such as domestic wastewater (47). In future, control of nutrients from non-point sources, e.g. urban and agricultural runoff will have to be initiated to maintain or restore a desirable level of water quality in wetlands and rivers (47). It is again stressed that prevention is better than cure.

Measures recommended to reduce nutrient input to water bodies are.

i diverting nutrients, e.g. sewage, sewage treatment plant effluents, leachates from waste disposal sites, agricultural effluents, urban stormwater away from water bodies (see Household effluent, page 29; Waste disposal sites – domestic, page 30 ; Waste disposal sites – industrial, page 31 ; Agriculture – point sources, page 32; Urban runoff, page 34);

ii removing nutrients from sewage (especially treatment to remove phosphorus) (46, 108, 109).

iii using non-phosphate (or low phosphate) detergents (43);

iv improving agricultural practices (including methods and rates of applying fertilizers, and handling of animal wastes (43, 46). (See Agriculture – non-point sources, page 32).

It is doubtful if eutrophication is a reversible process on any practical timescale, although some lakes have shown improvement in response to diversion of sewage or other remedial action (46, 105).

Once a wetland shows signs of eutrophication, the following steps may help to remedy the problem, in conjunction with reduction in further nutrient imput as outlined above:

i removal of nutrients by flushing a small water body with large volumes of water low in nutrients (46);

ii removal of nutrients by dredging and removing sediments high in nutrients (43, 111). This could have added benefit in deepening the lake (46);

iii removal of nutrients by use of lake water to irrigate a vegetation buffer around the lake, provided fresh water low in nutrients is used to maintain the water level in the lake (112);

iv removal of nutrients by removing excessive plant growth and debris (43). Efficient harvesting of macrophytes, plankton and fish and marketing as useful products could have economic value (46, 113). Fish can be used to reduce vegetation (111);

v application of chemicals to destroy algal growth. However, although this method has been used extensively, there is inadequate information on residues of toxicants, rates of breakdown, and long-term effects on aquatic ecosystems (46). This method is therefore not favoured (112);

vi artificial circulation of water (43);

vii oxygenation of water with compressed air to slow the release of nutrients at the sediment surface (111);

viii aeration of water by spraying through jets to reduce nuisance odours such as hydrogen sulphide, which is generated under anaerobic conditions (112);

ix in the case of estuaries increase the nutrient export from the estuary.

SOIL EROSION

i Soil erosion in the wetland catchment, which would carry sediments and pollutants into the water body and alter drainage patterns, should be controlled by:
- redirection or detention of the water causing the scouring (114);
- restricting clearing of vegetation and, if necessary, establishment of vegetation cover, especially on slopes or high ground;
- mulching areas prone to erosion, e.g., with straw, to reduce the quantity of runoff;
- recontouring of eroded channels by filling and/or earthworks (114);
- maintenance of a buffer zone of vegetation between cleared or cultivated areas and the wetland, to reduce water runoff velocity and trap suspended sediments;
- modification of slope effects by contouring or terracing;
- fire control techniques (115);
- limiting stock numbers according to the carrying capacity of the area, to prevent overgrazing and removal of ground cover (115);
- restricting other activities such as construction, use of off-road vehicles, in areas prone to erosion. The Environment Protection Authority of Victoria has recommended that subdivision of land with a slope greater than 20% should be prohibited, and development should not occur on poor load-bearing soils.

ii The possible effects of siltation of major potable water resources and of surface waters flowing into National Parks, nature reserves, wetlands and other forms should be considered before vacant Crown land is released for agriculture. If the effects were assessed to be significant, preventative measures as outlined above should be used. Should these not be feasible or practical, the anticipated social and economic benefits of the proposed development should be weighed against the value of the water resource to the community before allowing the release.

iii Erosion of the banks of the wetland itself should be controlled, for example by:
- protecting foreshore vegetation (79, 80);
- limiting access points, e.g. for recreational use or stock watering, and re-establishing ground cover in these cleared access areas.

  Measures can include walkways to watering points, pumping of water to troughs, regulation of stocking rates, and fencing of areas to allow regeneration (80);
- restricting the removal from river banks of snags and stumps which retard flow and promote deposition of sediment (114).
- limiting the use of power boats on parts of rivers or lakes where the foreshore is prone to erosion, as the wash against the shore accelerates the process;
- re-establishing marginal vegetation, e.g. trees, reeds and rushes, in areas already subject to erosion, if necessary in conjunction with the use of sand bags to prevent further erosion until the reeds become established; brush

mats or dumped rock riprap may also provide protection (114), as can anchored fallen trees (116). Protection and rehabilitation measures have been moderately successful in the Swan River;

- considering the effect on stream bank erosion in siting storm water outlets (97);
- consideration of possible erosion effects prior to any stream "improvement", desnagging, or other flood control works. It is recommended that minimal straightening and channel reshaping be undertaken (79, 80) and natural stream morphology be emulated in drainage design (79);
- river alignment fencing. Collection of small debris along a fence causes a differential velocity, and the silt load is dropped behind the fence (116);

use of rock chutes, with a gradient of not less than 4 horizontally to 1 vertically to check stream bed erosion (116).

WATER LEVEL CHANGES

Water supply–groundwater. Many Western Australian wetlands are ephemeral, i.e. dry-up in summer, but others, mostly in sandy terrain, are surface expressions of the water table and tend to retain water the year round, although the level may fluctuate depending on previous seasons.

Intensive groundwater extraction in the vicinity of a wetland may affect groundwater flow to it.

i If an extraction scheme must, for developmental, engineering or economic reasons, be established in a wetland area, then the value of the wetland should be assessed according to the criteria given on page

ii If the wetland has a value that necessitates its preservation (in some form), a number of engineering options should be considered, for example:

- The borefield layout could be placed in such a manner as to minimize the effect of groundwater depression on the wetland;
- The pumping strategy of the borefield might be manipulated in such a manner as to minimize adverse effects;
- The water level or volume of water in a wetland may be maintained by deepening;
- Some groundwater could be diverted from the borefield to the wetland to maintain water levels. Artificial recharge of lakes has been shown to be physically and chemically possible (117), but may prove to be expensive. The daily water loss from some refilled Perth lakes ranges from about 5 mm in lakes with relatively impermeable beds, to 10 to 20 mm in those with greater permeability (117). The permeability is influenced by the amount of organic material present in the lake bed–the more organic material the less permeable the bottom–and this is therefore an important consideration if lake beds are to be mined, excavated or dredged, whether for beautification or for deepening.

  The water loss, or leakage rate, from the lake is also larger if the water level is maintained at a greater height above the groundwater table (117).

iii Artificial lakes may be made impermeable by lining with clay, but this is expensive even on a small scale, and raises problems of salt and nutrient concentration in the summer and overflow in winter (particularly if the lake performs a function as a compensating basin for winter stormwater runoff) (117).

iv The artificial maintenance of the wetland by the pumping in of collected storm runoff, (this option is practical in wetlands adjacent to urban areas and where water quality is not critical).

v The artificial maintenance by the re-use of treated effluents.

vi The options being engineering ones, the developers of groundwater resources should work in full consultation with those whose task it is to assess the environmental value of a wetland. The appropriate option or combination of options for any particular case is dependent on site and aquifer conditions, other engineering aspects and economic considerations.

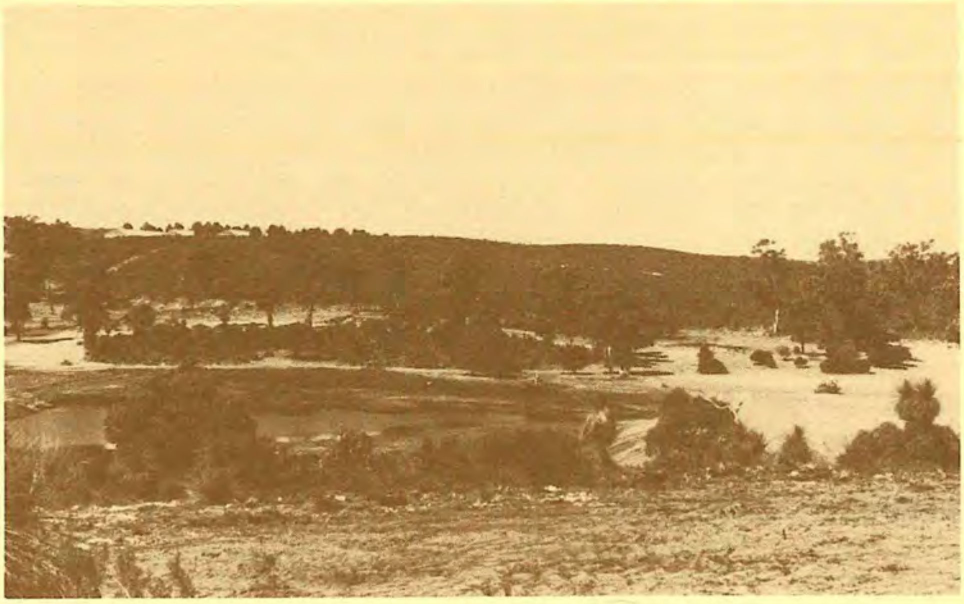
Water supply: surface water

i The effects of the hydrological changes on the ecosystem, both up and downstream from a proposed dam should be assessed prior to construction (see ref. 53).

ii Operation of dams should include measures to reduce harmful downstream effects, e.g. release of water to maintain stream flows.

Clearing

i The effects of clearing on the water table should be assessed prior to release of further areas of vacant Crown land for agricultural development (see Salination below), or approval of other developments (e.g. mining, forestry) which involve removal of vegetation on a large scale.



Water level manipulation

i Manipulation of the water regime, for example by dykes, dams, deepening selected areas, recharge with bore water, or control of gates in drains, should be considered a primary tool in the management of wetlands. The primary control over wetland vegetation, and hence fauna, is through the water level (15).

ii Valuable wetlands falling within drainage schemes should be managed to ensure an adequate water supply, both in terms of depth and period of flooding; for example Murphy's Swamp on the Murray River near Echuca in Victoria is managed for multipurpose use for wildlife preservation, drainage and irrigation water supply (118). In Western Australia a management programme has been carried out near Busselton (55).

ii Where estuarine wetlands are already cut off from tidal influence by flood gates, a revised schedule of flood gate operation should be introduced to allow for tidal flushing of wetlands (4).

SALINATION

The management of most wetlands depends on control of the catchments feeding water to them. In the case of salination, management depends on control over the extent of clearing and the ability to introduce rehabilitation programmes, e.g. revegetation, to reduce salination where this is already happening.

This may be relatively easily brought about in the higher rainfall areas where the catchments lie in State Forest or gazetted water control areas. However, the conservative management of the saline wetlands on the inland areas poses considerable problems since their catchments for the most part are farmlands in private ownership.

- i Land use planning should take into account the potential salination consequences of clearing of native vegetation. The objective should be to develop a management programme that ensures the minimal release of salt into catchment areas and associated water systems, whether they are in the immediate vicinity or remote from the proposed developments.
- ii The possible effects of salination of major potable water resources, or of ground and surface waters flowing into National Parks, wetlands, nature reserves or other farms, should be taken into account before further vacant Crown land is released for agriculture. If the subject land is located in a catchment area, and clearing is likely to lead to a significant lowering of water quality, preventative measures should be taken. If these, such as restricted clearing, were not feasible, the release should not proceed (see ref. 21).
- iii It is difficult to assess the potential salination consequences arising from clearing of vegetation in a particular area of land as many factors are involved. These include soil types, topography, rainfall and proximity to water systems. As a general guide, however, clearing of native vegetation should be avoided in catchment areas, particularly in deep lateritic zones, where salt storage is high.
- iv If for economic reasons clearing has to proceed, then due consideration should be given to schemes such as selective clearing, whereby the removal of vegetation is restricted to areas as distant as practical from water courses and to areas where salt storage is lowest, as well as to other techniques as they are proven in various regimes. In Western Australia legislation exists to prevent clearing in certain catchment areas. Compensating land is offered to farmers affected by these bans (119).

AESTHETIC DISRUPTION

The value of aesthetic improvement is a difficult thing to cost in economic terms. The value of aesthetic improvement is long-term but will become self renewing.

The aesthetic environment of an area to be developed should be preserved, to the greatest degree possible, by integrating all facets of the development with the natural order. This could be achieved by, for example:

- i the appropriate siting of construction according to the natural vegetation and contours of the land, to reduce its conspicuous facets;
- ii the preservation of as much as possible of the native vegetation, particularly around the foreshore of the wetland and in areas of high natural scenic value or with special or unusual vegetation or other features and, if necessary, enhancement the vegetation by the planting of appropriate species;
- iii the prevention of bank and foreshore erosion (see Soil Erosion, page 35);
- iv the prevention of pollution of the water body and its surrounds, e.g. by litter, urban stormwater discharge (see Urban Runoff, page 34), septic tank leachates (which could lead to unsightly deterioration of water quality, see Household Effluent, page 29), and waste disposal sites (see Waste Disposal Sites–Domestic, Industrial and Mining, page 31).

AQUATIC WEEDS

- i In view of the potential adverse effects of aquatic weeds on wetlands it is imperative to include in wetland management programmes the undertaking of regular policing to ensure that any outbreak is curbed in its early stage. It is suggested that the Agricultural Protection Board's assistance be sought particularly in respect of wetlands of significantly high conservation value.

  Details of control measures are also given in ref. 59 and 61.

ii Major obstacles to management of weeds in Australia are the lack of a common approach to the problem, and lack of basic ecological knowledge necessary for rational management (59). Research in this field should therefore be encouraged.

iii Trade in aquatic plants, e.g. for aquariums, should be confined to species which do not cause weed problems if introduced into wetland areas.

iv As with insecticides, see below, the use of herbicides for weed control in or near wetlands should be approached with caution (see ref. 61).

v Alternative methods of control, such as biological control and manipulation of environmental factors, e.g. light, nutrient input, water level, should be investigated (see pages 59, 61, 120).

vi The possibility of using the excessive plant matter produced by aquatic weeds as fertilizers, or in the purification of waste water, should be investigated.

vii Measures to minimize aquatic weed problems should be incorporated into the earliest stages of water resource development planning. (More detailed recommendations are given in ref. 59).

INSECT PEST CONTROL

i Wetlands which are known to be significant mosquito breeding sites, e.g. the samphire-heath tidal flats associated with the Swan, Canning, Murray, Serpentine and Collie Rivers, and the Peel, Harvey and Leschenault estuaries, should be evaluated to determine their worth as wetland environments, so that conservation needs can be balanced against the need for mosquito control (63).

ii The potential of a wetland as a mosquito breeding area should be taken into account before consideration of locating residential development in proximity to it. When the wetland has outstanding value, particularly as a wildlife habitat, its preservation may be of greater value to the community at large than would the adjacent residential development which could create pressure for mosquito control measures which are destructive to wildlife.

iii When considering the use of chemicals for insect control in and near wetlands, the approach should be one of caution in the light of the lack of information on the possible effects of many insecticides on aquatic systems.

iv The use of chemicals should be avoided wherever practical. If there is no alternative, then the chemical chosen should, if possible, have a low persistence and be selective against the target pest. It is noted that the larvicide Abate has relatively low toxicity to non-target organisms in comparison with other available insecticides (63).

v It is recommended that alternative control techniques, including the source reduction technique of ditching for control of species breeding on tidal flats, be considered for local evaluation (63). An ecological approach, relating mosquito management to the wetland food web, has been shown to be effective in some waterfowl impoundments (121).

vi Dense vegetation around swamps may be used as a barrier to prevent midges leaving the water and annoying people in the vicinity.

vii The prevailing winds which may blow insect pests into residential areas must be considered when locating a residential development.

CONCLUDING COMMENTS

The guidelines set out in this Bulletin are based on the first edition of the guidelines released in July, 1977; they have been up-dated to include relevant information which has since become available, and in the light of comments received from readers.

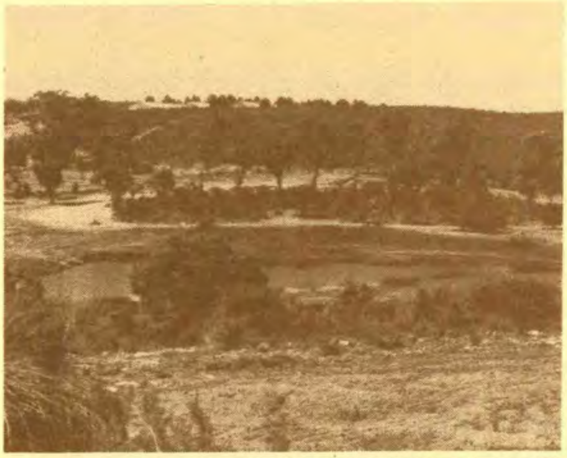
As numerous interacting factors must be assessed in the development of adequate conservation and management plans for wetlands, the guidelines are of necessity lengthy and complex. For this reason a glossary of terms, and list of useful references for further reading, have been included to facilitate access to information.

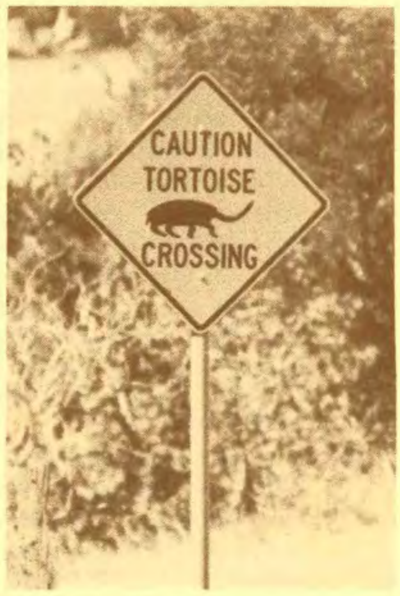
ACKNOWLEDGEMENTS

The production of a revised edition of this booklet can result only from the work of numerous persons who are both knowledgeable technically and motivated personally. Those involved are too numerous to list all individually.

However, the work and co-operation of the members of the Wetlands Advisory Committee and of other Government and non-Government personnel must be acknowledged.

The efforts of Mrs. Karen Majer in the production of this revised edition are particularly acknowledged.





GLOSSARY

Algae: a group of chlorophyll-bearing plants. Many are microscopic (often being single cells) but some can be large. Mostly aquatic. The green slime found in some pools is a form of algae (123).

Aquatic: living, growing in or on water.

Aerobic: needing oxygen for life (aerobic organisms); an environment where plenty of oxygen is available (aerobic environment).

Anaerobic: no free oxygen available for use. Some organisms can live in environments where there is no free oxygen (anaerobic environment). Anaerobic conditions often produce foul smells.

Benthic region: the bottom of a body of water (123).

Bloom: a population explosion of algae when an excess of a limiting nutrient becomes available.

B.O.D.: Biochemical or Biological Oxygen Demand. A measure of the amount of oxygen utilised during the biochemical degradation of organic material. The result (usually measured in mg/l) gives some measure of the amount of biologically degradable organic material in polluted water, e.g. clean creek water B.O.D. 0-2 mg/l, raw sewage B.O.D. 250-350 mg/l.

Biomass: the total living matter in an ecosystem, e.g. a lake, synonymous with standing crop, stock, standing stock.

Catchment: the surface area from which water runoff to a river or any other collecting reservoir, e.g. swamp, groundwater.

Cone of depression: the volume around a well where water is removed from the surrounding sand. This produces a conical depression in the water table with the well in the centre of the depression.

Deoxygenation: a process by which oxygen is removed from a system.

Dilute: reduce the concentration of a solution by adding more solvent, e.g. fresh-water will dilute sea-water.

Dissolved Oxygen Concentration: a measure of the amount of oxygen dissolved in a particular body of water. The maximum D.O. concentration is about 9 mg/l however, this is dependent upon temperature and pressure.

Detritus: in biology is used to describe the decomposing debris from plants and animals.

Ecosystem: a term used to describe a specific environment, e.g. lake, to include all the biological, chemical and physical resources and the interrelationships and dependencies that occur between those resources.

Environment: the physical surroundings in which an organism or group of organisms live.

Effluent: the liquid, solid, or gaseous products discharged by a process, treated or untreated.

Erosion: the levelling of the land surface by the weathering, chemical breakdown and transportation of rock and soil particles under the influence of gravity, wind and running water.

Estuary: estuaries are the tidal portions of river mouths, bays and coastal lagoons, irrespective of whether they are dominated by hypersaline, marine or fresh water. The estuary includes the body of tidal water, the floor of the estuary, the intertidal wetlands and their entire biota, including both permanent and temporary residents.

Eutrophic: water bodies rich in dissolved nutrient. Also used to describe water with low dissolved oxygen concentration.

Eutrophication: the nutrient enrichment of water causes certain symptomatic changes to the quality and type of life in a water body. Some of these changes are increased production of algae and macrophytes, lowering of dissolved oxygen concentration, death or disappearance of fish deterioration of water quality. Eutrophic waters often become anaerobic (123, 124, 125).

Ephemeral wetland: a wetland that contains water for only part of the year.

Evapotranspiration: the loss of water given off from plants by evaporation and transpiration from leaves.

Fauna: the animal life of a geological period or of a region.

Feedlot: a small holding paddock where domestic animals are fed with introduced feed rather than by natural grazing.

Fertilizers: materials which, when added to soil, stimulate the growth of crops. Natural organic fertilizers applied today include manure, compost and sawdust while inorganic fertilizers include crushed limestone, gypsum, sulphur and rock phosphate. In addition, vast amounts of manufactured chemical compounds of nitrogen, potassium, phosphorus and sulphure are applied. Many manufactured chemicals are soluble and easily leached away. Nitrates and phosphates (compounds of nitrogen and phosphorus) can be dangerous to health and induce eutrophication in water bodies.

Flood plain: relatively flat portion of a river valley, adjacent to the river channel, built of sediments carried by the river and which is covered with water when the river overflows its banks.

Flora: the plant life of a geological period or of a region; corresponds to the term fauna for animal life.

Food Chain or Food Web: a chain or web of organisms through which energy and nutrients are transferred; each link in the chain feeds on (i.e. obtains energy and nutrients from) the one preceding it and, in turn, is eaten by and provides energy and nutrients for, the one following it. An ecosystem consists of numerous food chains, although two major categories of food chain are the grazing based food chain and the detritus based food chain.

Groundwater: water which occupies the pores and crevices of rock and soil, as opposed to surface-water which runs off into streams. Groundwater is particularly vulnerable to pollution because of its low self-cleansing capacity. Groundwater is classified according to its source. An unconfined groundwater aquifer occurs where direct seepage from the surface meets the water table. Confined groundwater aquifers occur where water-bearing rock is overlain with an impermeable layer of rock or clay. This aquifer is filled from a long distance away where the rock bearing the water is exposed on the surface.

Habitat: a physical portion of the environment that is inhabited by an organism or population of organisms. A habitat is characterised by a relative uniformity of the physical environment and fairly close interaction of all the biological species involved.

Herbicide; a chemical agent used to kill plants.

Hydrology: a study of water movements, quality and distribution utilisation and condition, above, on and below the ground.

Hydrological Cycle: the continual exchange of water between the earth and the atmosphere. Since the height of the ocean surfaces remains essentially unchanged from year to year, evaporation from the oceans must equal the rainfall over the oceans plus the run-off from rivers and streams and effluent discharges.

Hypersaline: water with total soluble salts concentration greater than seawater (35,000 ppm).

Insecticides: natural (e.g. derris, pyrethrins) or synthetic chemical agent for destroying insects.

Landfill: where solid waste is deposited upon the land. Sites being used for such disposal include:

1. Mineral excavations
2. Low-lying land
3. Valleys
4. Areas involving the reclamation of land from water
5. Flat land to build up a feature.

If landfill sites are left uncovered then problems such as fires, scavengers, disease and wind-borne rubbish can result. To overcome these problems sanitary landfill is used. Generally, in a sanitary landfill scheme, refuse is tipped in trenches or cells prepared to such a width that the daily input refuse can be effectively covered, presenting a clean face each day. It is essential that the refuse be adequately covered with soil and compacted to allow traffic over the fill.

This controlled landfill method is known in the United Kingdom as "controlled tipping" and in the United States and Australia as "sanitary landfill.' Siting of landfill sites is important to ensure there is no leachate contamination of groundwater.

Landscape or Amenity Conservation: the safeguarding for public enjoyment of scenery or landscape, and of areas suited to outdoor recreation, tourism, field sports, and similar activities; the concept includes the preservation and enhancement not only of what has been inherited but the provision of new amenities and facilities.

Leachate: see leaching.

Leaching: the process by which materials such as organic matter and mineral salts are washed out of a layer of soil or dumped material by being dissolved by or suspended in percolating rainwater; the material washed out is known as leachate. Leachate can be detrimental to ground or surface water by introducing bacteria and viruses, toxic organic compounds, heavy metals and nutrients into these waterways.

Lentic waters: standing water bodies, e.g. lakes, as opposed to lotic (flowing) waters.

Limiting Nutrient: a nutrient essential for growth, in the case of algae, nitrogen or phosphorus; that, because of its short supply restricts or limits the amount of growth that can occur. When an excess of this nutrient becomes available a bloom can occur.

Limnology: the study of the biological, chemical and physical aspects of inland water.

Lotic waters: flowing waters. See Lentic.

Macrophyte: a plant which can be seen by the unaided eye.

Nitrates (NO_3^-): salts of nitric acid. Most common sources of addition of nitrates to the environment are nitrogen fertilisers. Nitrates cause degradation of the environment by causing 'algal blooms' (see eutrophication), as has occurred in Cockburn Sound. If nitrates are in sufficient concentration in drinking water they can cause a disease which inhibits the capacity of the blood to carry oxygen in infants.

Nutrients: materials conveying, serving as, or providing nourishment to some organisms.

Oligotrophic: applied to a body of water containing relatively low amounts of nutrients, and usually with considerable dissolved oxygen in the bottom waters. See Eutrophic. Water with a small supply of nutrients and a low organic production.

Pesticides: collective name for a variety of insecticides, fungicides, herbicides, fumigants and rodenticides.

pH: a measure of how acid or basic (sometimes called alkaline) a solution is. Neutral pH is 7.0, highly acid 1.0, highly basic 14.0. Unpolluted rivers have a pH range of 5.0-8.5. Mineral dump runoff may be highly acidic with a pH of 2.0. Sewage authorities usually set limits of pH 5.0 and pH 10.0 for sewage that comes to them for treatment. Technically pH is a measure of the hydrogen ion concentration of a solution.

Phosphates (PO_4^{3-}): essential nutrients for plants and normal constituents of the food of man and animals. The principal man-made sources are sewage, agricultural run-off and detergent "builders". In excessive amounts considered a major factor in the process of eutrophication resulting in excessive growth of aquatic plants, depletion of oxygen, loss of fish and general degradation of water quality.

Photosynthesis: the formation in chlorophyll-containing (green) plants of carbohydrates from carbon dioxide and water; simultaneously, free oxygen is released into the atmosphere. The energy needed for photosynthesis is supplied to green plants by sunlight.

Phytoplankton: the plant portion of the plankton, usually consisting of the microscopic algae (see zooplankton).

Plankton: animals and plants which move or drift in the water at the mercy of water movements.

Pollution: any direct or indirect alteration of the physical, chemical, thermal, biological, or radioactive properties of any part of the environment by discharging, emitting or depositing wastes or substances so as to affect any beneficial use adversely, to cause a condition which is hazardous or potentially hazardous to public health, safety or welfare, or to animals, birds, wildlife, fish or aquatic life, or to plants.

Population: an assemblage of organisms of a particular species in one location.

ppm: parts per million, a measure of concentration. It is used as an equivalent to mg/l.

Reclamation: the process of converting land to some other use. Reclamation is most often used to describe the process where the land is converted to be of more immediate use to man. This however may not be the most valuable, e.g. filling a wetland with garbage may produce playing fields but may also pollute the groundwater below.

Run-off: the discharge of water through surface streams into larger watercourses.

Salinity: the measure of the total soluble (or dissolved) salt, i.e. mineral constituents, in water. Natural sources of salinity are sea spray in the atmosphere and water passing over rock formations and soil containing soluble salts.

Other sources of salinity include domestic and industrial wastes and mine water. Water containing more than 500 ppm of dissolved solids is not considered desirable for domestic supplies. Water containing more than about 2,000 ppm is generally considered to be unsuitable for irrigation under average conditions, in the long term. High levels of salinity in soil water in Australia are a major environmental hazard associated with agriculture, and particularly with irrigation. In many areas the groundwater is naturally saline. The clearing of natural vegetation on land in southern Australia for agriculture and replacement with introduced grasses has brought, through reduced evapotranspiration, a resulting rise in the water table. In consequence, in many localities, considerable areas have gone out of production.

Sanitary landfill: see Landfill.

Sediment: sand, clay, silt, pebbles and organic material carried in water or by the wind.

Sedimentation: the process where there is deposition of sediment.

Septic tank: a watertight tank where domestic waste water is held allowing some of the solids to settle to form a sludge, or float to form a scum. The liquid effluent is then passed into an effluent distribution system, e.g. leach drain, soak well or pipe network. The sludge decomposes under anaerobic bacterial action. The sludge gradually builds up and must be periodically removed to maintain efficient operation of the tank.

Sewage: domestic waste water. A dilute suspension (99% water) containing faeces, urine, grit, vegetable material, soaps and detergents, paper, rags, etc. The term foul sewage is sometimes used to distinguish between sewerage carrying sewage as defined above and a sewerage carrying stormwater.

Sewerage: a network of pipes to carry sewage.

Stormwater: localised surface runoff water as a result of rainfall.

Sullage: household grey water, water from sinks, laundries, baths, etc. excluding toilets.

Suspension: a fluid containing solid or liquid particles which are not dissolved or floating, but do not settle out from the fluid because they are kept moving by the movement of the fluid molecules.

Terrestrial: living or growing on land or on the ground.

Thermal Pollution: the transfer of heat from industrial processes to bodies of water or air in such quantities as to be detrimental to the environment. Effluents having a significant effect on the temperature of a river may affect the oxygen content of the water and accentuate other adverse conditions. At sufficiently high temperatures, fish may die; fish populations could be destroyed also by the lethal effects of increased temperature either on another animal on which they feed or on their own spawn. In the presence of sufficient oxygen, it appears that heat alone will shorten the stretch of river affected by the pollution load by accelerating purification. In a river with 'light' pollution load, this would be beneficial; however, in a river with a 'heavy' pollution load the effect is likely to be harmful. The harmful effects may include a reduction of the oxygen concentration below the level critical to organisms living in the water. A sufficient loss of oxygen will result in anaerobic conditions. Sewage fungus, found frequently in polluted rivers, grows rapidly in warmed water.

Turbidity: clouding of water due to suspended material in the water causing a reduction in the transmission of light. Reduction in light can cause death of water plants and animals.

Water Table: the surface of the groundwater. The surface is uneven and variable; during wet weather it tends to rise, falling during dry weather. The lowest level to which a water table falls in any locality is known as the permanent water table.

Weedicide: a chemical weed killer.

Zooplankton: the animal portion of the plankton.

REFERENCES

1. ALLEN, R. (1975) Saving Wetlands for a Rainy Day. New Scientist 68 (980): 703-704.
2. WETLANDS ADVISORY COMMITTEE (1977) The Status of Wetland Reserves in System 6. Report of the Wetlands Advisory Committee to the Environmental Protection Authority (Western Australia).
3. RIGGERT, T.L. (1974) Man and Nature: Conservation of Wetland Areas. A.C.W.W. Triennial Conference, Perth, October, 1974. Department of Fisheries and Fauna, Western Australia.
4. AUSTRALIAN MARINE SCIENCES ASSOCIATION (1977) Guidelines for the Protection and Management of Estuaries and Estuarine Wetlands. AMSA East Melbourne.
5. BUCKMASTER, D.E. (1973) Wetlands and Fisheries. Victoria's Resources 15 (1): 23-27.
6. BROWN, P.G. (1973) Wetlands and the Community. Victoria's Resources 15 (1): 2-5.
7. COWLING, S.J. (1973) Waterbird Management in Victoria. Victoria's Resources 15 (1): 8-12.
8. SHAW, N.J. (1973) Wetlands and Educational Resources. Victoria's Resources 15 (1): 13-15.
9. FORBES & FITZHARDINGE (1977) Swan and Canning Rivers Activity Study. Prepared by Forbes and Fitzhardinge, Architects and Planners, for the Department of Conservation and Environment, Western Australia.
10. ENVIRONMENTAL PROTECTION AUTHORITY (1977) Guidelines for an Environmental Protection Policy on the Coastal Zone in Western Australia. Working Draft for Public Discussion. Environmental Protection Authority, Western Australia; June, 1977.
11. GOODRICK, G. (1970) A Survey of Wetlands of Coastal New South Wales. Tech. Memo Division of Wildlife Research, C.S.I.R.O. Aust. No. 5.
12. WILDLIFE SOCIETY (1977) Wildlife Management Techniques. Wildlife Society, Washington, D.C.
13. ELKINGTON, J.B. (1977) The Impact of Development Projects on Estuarine and Other Wetland Ecosystems. Environmental Conservation 4 (2): 135-144.
14. TERECO CORPORATION (1976) Impacts of Construction Activities in Wetlands in the United States. Prepared for the U.S. Environmental Protection Agency, Report Number EPA 600/3-76-045.
15. HASLAM, S.M. (1973(a)) The Management of British Wetlands Economic and Amenity Use. Journal of Environmental Management 1: 303-320.
16. INTERNATIONAL UNION FOR CONSERVATION OF NATURE AND NATURAL RESOURCES (1977) List of Wetlands of international importance designated by the contracting parties. Morges, Switzerland: 8pp.
17. LONGHURST, A.R. (1977) European Wetland Campaign. Marine Pollution Bulletin 8 (3): 50.
18. CONVENTION ON WETLANDS OF INTERNATIONAL IMPORTANCE ESPECIALLY AS WATERFOWL HABITAT, RAMSAR FEBRUARY (1971). Department of Foreign Affairs, Canberra, A.C.T. Treaty Series 1975, No. 48.
19. MALCOLM. T.L. (1976) The Value to Agriculture of Wetlands in System 6. (Department of Agriculture, Western Australia). Unpublished report to the Wetlands Advisory Committee.
20. RIGGERT, T.L. (1966) A Study of the Wetlands of the Swan Coastal Plain—a pilot study of the wetlands in Western Australia with particular reference to their use by waterfowl. Department of Fisheries and Fauna, Western Australia.
21. ENVIRONMENTAL PROTECTION AUTHORITY (1979) Statement by the Environmental Protection Authority on Vacant Crown Land Proposed for Agriculture. Environmental Protection Authority, Western Australia.
22. O'CONNOR, J.A. (1975) Saving Melbourne's Creeks. Article based on paper given at Northern Melbourne Regional Waterways Seminar, Preston Institute of Technology, 29 June, 1975. In: Community 2/4:7.
23. LEOPOLD, L.B. (1968) The Hydrologic Effects of Urban Land Use. In: Hydrology for Urban Land Planning—a Guidebook on the Hydrologic Effects of Urban Land Use. U.S. Geological Survey Circular 554: 1-18.

24. STATE POLLUTION CONTROL COMMISSION, NEW SOUTH WALES (1978) Environmental Impact Assessment of Flood Mitigation Works and Dams. Government Printer, N.S.W.
25. MARZOLF, G.R. (1978) The Potential Effects of Clearing and Snagging on Stream Ecosystems. Biological Services Program, Fish and Wildlife Service, U.S. Department of the Interior. FW S/O BS–78/14 January 1978: 31pp.
26. GILPIN, A. (1976) Dictionary of Environmental Terms. University of Queensland Press, Brisbane.
27. PUBLIC WORKS DEPARTMENT (1974) A Report of Community Waste in the Perth Metropolitan Region. Public Works Department, Western Australia.
28. ORR, N. (1979) Sanitary Landfill Sites and Wetlands. Unpublished notes.
29. ESTUARINE AND MARINE ADVISORY COMMITTEE (1976) Anticipated Effects of Dredging in the Blackwood River Estuary. A Report by the Estuarine and Marine Advisory Committee to the Environmental Protection Authority, Western Australia.
30. LINDALL, W.N., TRENT, L. (1975) Housing Development Canals in the Coastal Zone of the Gulf of Mexico: Ecological Consequences, Regulations and Recommendations. MFR Paper 1163, From: Marine Fisheries Review 37 (10), 19:24.
31. WESTMAN, W.E. (1975) The Ecology of Canal Estates. Search 6 (11, 12): 491-497.
32. THOMSON, J.M. (1976) Environmental Effects of Canal Estates, Proceedings of the Symposium of Canal Estates, Institution of Engineers, (Qld Division) Australia. April 28 1976: 5pp.
33. BUTLER, R.G., ORLOB, G.T. (1954) Underground Movement of Bacterial and Chemical Pollutants. Journal American Water Works Association 46 (2): 97-111.
34. MORRISON, S.M. & MARTIN, K.L. (1977) Pathogen Survival in Soils Receiving Waste. Land as a Waste Management Alternative. Editor: R.C. Loehr; Ann Arbor Science Publications Inc., Michigan: 371-389.
35. McGAUHEY, P.H. (1968) Man-made Contamination Hazards. Groundwater 6 (3): 10-13.
36. DEPARTMENT OF ENVIRONMENT (1970) What Pollutes Our Water? Environment Information 4.
37. IVESON, J.B. (1976) Local and International Aspects of Salmonellosis. West Australian Health Surveyor, March, 1976: 3-20.
38. HARMS, L.L., MIDDAUGH, P., DORNBUSH, J., ANDERSON, J.R. (1975) Agricultural Runoff Pollutes Surface Waters. Part I. Bacteriological Quality of Surface Runoff from Agricultural Land, Part II. Water and Sewage Works, Oct. 1975: 84-85.
39. WEBER, J.B. (1977) The Pesticide Scorecard. Environmental Science and Technology 11 (8): 756-761.
40. UNIVERSITY OF NEW SOUTH WALES (1970) N.S.W. University Water Research Laboratory Report 120.
41. HART, B.T. (1975) Urban Stormwater Quality. Water in the Urban Environment. Australian Water and Wastewater Assoc. Summer School 3rd-7th Feb., 1975, Canberra, A.C.T. National Library of Australia. 8pp.
42. LLOYD, R.D.C. (1975) Improvement of Quality of Stormwater Discharge to Rivers and Lakes. Water in the Urban Environment. Australian Water and Wastewater Assoc. Summer School 3rd-7th Feb., 1975, Canberra, A.C.T. National Library of Australia. 12pp.
43. HART, B.T. A Compilation of Australian Water Quality Criteria. Australian Water Resource Council Technical Paper No. 7. Australian Government Publishing Service, Canberra. 350pp.
44. ALLEN, M.J. & GELDRICH, E.E. (1975) Bacteriological Criteria for Groundwater Quality. Groundwater 13 (1): 45-51.
45. MILLER, F.P. (1970) Pollution–are fertilizers at fault? Crops and Soils 22 (9): 15-20.
46. NATIONAL ACADEMY OF SCIENCES (1969) Eutrophication: Causes, Consequences, Correctives. International Symposium on Eutrophication. University of Wisconsin, Madison, 1967.
47. LEE, G.F., RAST, W., JONES, R.A. (1978) Eutrophication of Water Bodies: Insights for an age-old problem. Environmental Science and Technology Water Report 12, (8): 900-908.
48. LIKENS, G.E. (editor) (1972) Nutrients and Eutrophication: The Limiting Nutrient Controversy. Proceedings of the Symposium on Nutrients and Eutrophication–The

Limiting Nutrient Controversy. W.K. Kellogg Biological Station, Michigan State University, 11-12 Feb., 1971. American Society of Limnology and Oceanography Inc. Publications Office, Allen Press, Inc. Lawrence, Kansas, 66044.
49. ALLEN, A.D. (1976) Hydrogeology of superficial formulations. In: Groundwater Resources of the Swan Coastal Plain. Proceedings of a Symposium jointly organised by E.P.A. and C.S.I.R.O. Murdoch University, Western Australia, 1975 (Ed. B.A. Carbon): 12-13.
50. BURTON, C.A. (1976) Future water balance of the Swan Coastal Plain. In: Groundwater Resources of the Swan Coastal Plain. Proceedings of a Symposium jointly organized by E.P.A. and C.S.I.R.O. Murdoch University, Western Australia, 1975. (Ed. B.A. Carbon).
51. WESTERN AUSTRALIAN MUSEUM (1978) Faunal Studies of the Northern Swan Coastal Plain – A Consideration of Past and Future Changes. Report for the Department of Conservation and Environment, Western Australia.
52. ATKINSON-WILLES, G. (1969) Wildfowl and Recreation – A Balance of Requirements. British Water Supply 11: 5-15.
53. INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS (1972) Man-made Lakes as Modified Ecosystems. SCOPE Working Group on Man-Made Lakes, SCOPE Report 2.
54. ACKERMAN, W.C., WHITE, G.F. & WORTHINGTON, E.B., (ed) (1973) Man-Made Lakes: Their Problems and Environmental Effects. Geophysical monograph 17, American Geophysical Union, Washington, D.C.
55. SANDERS, C. (1976) Maintenance of Lakes and Aquifers. In: Groundwater Resources of the Swan Coastal Plain. Proceedings of a Symposium jointly organized by E.P.A., C.S.I.R.O., Murdoch University, Western Australia, 1975. (Ed. B.A. Carbon): 182-190.
56. TINGAY, A., TINGAY, S. & GOODSELL, J. (1977) Report of a Black Swan Conservation Programme in South-Western Australia. Emu 77: 185-187.
57. PECK, A.J. & HURLE, D.H. (1973) Chloride balance in some farmed and forested catchments in south-western Australia. Water Resources Research 9 (3): 648-657.
58. ANON (1975) Salt Problems in Perth's Hills. Ecos 4: 3-12. C.S.I.R.O. Environmental Research.
59. MITCHELL, D.S. (1978) Aquatic Weeds in Australian Inland Waters. Department of Environment, Housing and Community Development, Canberra.
60. DOUGLAS, G.W. (1977) Vermin and Noxious Weeds on Stream Frontages. In: Problems of Streams and Stream Frontages, Victoria's Resources 19 (1): 27-29.
61. MITCHELL, D.S. (Editor) (1974) Aquatic Vegetation and its Use and Control. U.N.E.S.C.O., PARIS.
62. WILLIAMS, W.D. (1977) The Australian Inland Aquatic Environment: A Background Review for Management Purposes. In: The Menace of Water Hyacinth and other Aquatic Weeds. Water Research Foundation of Australia, Symposium, Adelaide, S. Australia, 1977: 1-21.
63. BLAIR, A. (1979) Control of Mosquitoes and Non-Biting Midges in Perth and outer urban areas. Department of Conservation and Environment. Bulletin No. 66.
64. BLAIR, A.L. (1977) Mosquito Investigation Programme Within the Town of Canning. Department of Conservation and Environment, Western Australia.
65. BLAIR, A. (1978(a)) Mosquito Investigation No. 2. Shire of Wanneroo. Department of Conservation and Environment, Bulletin No. 36.
66. BLAIR, A.L. (1978(b)) A Means of Identifying the Common Mosquitoes of the Perth Metropolitan Area. Department of Conservation and Environment, Western Australia, Bulletin No. 42.
67. BLAIR, A.L. (1978(c)) Notes on the Chemical Control of Adult Mosquitoes. Department of Conservation and Environment, Western Australia, Bulletin No. 43.
68. WILSON, F. (1960) A Review of the Biological Control of Insects and Weeds in Australia and Australian New Guinea. Commonwealth Agricultural Bureaux, Farnham Royal, Bucks., England.
69. MAJER, K. (1979(a)) Wetlands of the Darling System: Wetlands in Recreation Reserves. Department of Conservation and Environment, Western Australia, Bulletin No. 59.
70. MAJER, K. (1979(b)) Wetlands of the Darling System: The Purposes and Vestings

of Wetland Reserves. Department of Conservation and Environment, Western Australia, Bulletin No. 60.
71. MAJER, K. (1979(c)) Wetlands of the Darling System: Wetlands in Conservation Reserves and National Parks. Department of Conservation and Environment, Western Australia, Bulletin No. 61.
72. MAJER, K. (1979(d)) Wetlands of the Darling System: Wetland Reserves and Their Management. Department of Conservation and Environment, Western Australia, Bulletin No. 62.
73. ANON (1976) Waterbird Areas in the Kerang Region. Water Talk 36: 3-4.
74. BROTCHIE, J.F. Urban development without spoiling creeks. Habitat 8:13.
75. BRIDGEWATER, P. List of plants suitable for planting around wetlands. Unpublished notes. Murdoch University 1980.
76. MARCHANT, N. List of plants suitable for planting around wetlands. Unpublished notes. W.A. Henbarium.
77. DILAJ, M., LENARD, J.F. (1975) Stop Leachate Problems. Water and Wastes Engineering, Oct. 1975: 27.
78. BRIGGS, S. (1977) Flood Mitigation. National Parks Journal 21: 5-9.
79. NUNALLY, N.R. (1978) Stream Renovation: An Alternative to Channelization. Environmental Management 2 (5): 403-411.
80. ZELMAN, M. (1977) Some Aspects of Management of Stream Frontages. In: Problems of Streams and Stream Frontages, Victoria's Resources 19 (1): 4-9.
81. HASTINGS, I. (1977) Maintaining Wildlife Values of Stream Frontages. In: Problems of Streams and Stream Frontages, Victoria's Resources 19 (1): 24-26.
82. ROGAN, P. (1977) Maintaining Wildlife Values in Streams. In: Problems of Streams and Stream Frontages, Victoria's Resources 19 (1): 24-26.
83. KELCEY, J.G. (1975) Industrial Development and Wildlife Conservation. Environmental Conservation 2 (2): 99-108.
84. CATCHPOLE, C.K., TYDEMAN, C.F. (1975) Gravel Pits as New Wetland Habitats for the Conservation of Breeding Bird Communities. Biol. Conserv. 8: 47-59.
85. ROOTH, J. (1975) Caribbean Flamingoes in a man-made habitat. In: Flamingoes. Editors: J. Kear and N. Duplaix-Hall.
86. KABAY, E.D. (1979) Formation of wetlands as a possible rehabilitation option for open cut mining in south west of Western Australia. Proceedings of the 1979 Workshop of the Australian Mining Industry Council held at The Lighthouse Inn, Bunbury, Western Australia, September 1979.
87. REID, A. (1977) Ducks and drakes with ponds and lakes. Habitat, Australia 5 (3): 22-26.
88. HASLAM, S.M. (1973(b)) The Management of British Wetlands II: Conservation. Journal of Environmental Management 1: 345-361.
89. MILLS, D., MACIVER, D. (1964) Wildfowl on hydro-electric reservoirs in the Scottish Highlands. (Fauna Reserves). Wildfowl Trust 15th Annual Report (1964).
90. ASTON, H.I. (1973) Bird Habitat in Wetlands. Victoria's Resources 15 (1): 16-19.
91. HAMOR, W.H., UHNG, H.G., COMPTON, L.V. (1967) Ponds and Marshes for Wild Ducks on Farms and Ranches in the Northern Plains.(U.S. Department of Agriculture Farmers Bulletin No. 2234 August 1968).
92. ATLANTIC WATERFOWL COUNCIL (1963) Waterfowl Habitat Development and Management Techniques Handbook. Habitat Management and Development Committee, Atlantic Waterfowl Council.
93. TOURBIER, J. & WESTMACOTT, R. (1976) Lakes and Ponds. Urban Land Institute, Washington, D.C. Technical Bulletin 72.
94. KRENKEL, P.A., HARRISON, J., BURDICK, J.C. III. (1976) Proceedings of the Speciality Conference on Dredging and its Environmental Effects. American Society of Civil Engineers, New York: 1035pp.
95. PISANO, M.A. (1976) Non-point sources of pollution: A Federal Perspective. Journal of the Environmental Engineering Division, June, 1976: 555-565.
96. PATTERSON, J.W., MINEAR, R.A. & NEDVED, T.K. (1971) United States National Technical Information Service P.B. 205-519.
97. ENVIRONMENT PROTECTION AUTHORITY (VICTORIA) (no date) Brief Summary of Environment Management Factors for Land-Use Planning (Unpublished).
98. PARKER, W.F., CARBON, B.A., GRUBB, W.A. (1979) Coliform Bacteria in Sandy

Soils beneath Septic Tank Sites in Perth, Western Australia. Australian Water Resources Council, Groundwater Pollution Conference, Preprint Papers. Perth, 19-23 Feb., 1979: 234-244.
99. WHELAN, B.R., BARROW, N.J., CARBON, B.A. Movement of phosphate and nitrogen from septic tank effluent in sandy soils near Perth, Western Australia. Australian Water Resources Council, Groundwater Pollution Conference, Preprint papers, Perth, 19-23 Feb., 1979: 226-233.
100. NATIONAL HEALTH AND MEDICAL RESEARCH COUNCIL (1975) Disposal of Wastes from Caravans and Caravan Parks. National Health and Medical Research Council, 81st Session, Oct., 1975. (unpublished recommendations).
101. GOEPPNER, J. (1975) Sanitary landfills–No place for leaching. Water and Wastes Engineering, September, 1975: 47-53.
102. McLELLAN, W.M., VICKERS, D.H., CHARBA, J.F., BERGSTROM, G.I. (1974) Environmental Impact Assessment of a Sanitary Landfill in a High Water Table Area. Purdue University Engineering Bulletin 145: 94-114.
103. WALKER, W.H. (1975) Effluent for Irrigation–A Need for Caution? Groundwater 13 (1): 11-15.
104. ANON (1975) Farm waste composting process. Effluent and Water Treatment Journal 15 (9): 482-488.
105. NEWBOLD, C. (1975) Herbicides in aquatic systems. Biological Conservation 7 (2): 97-118.
106. FIELD, R., LAGER, J.A. (1975) Urban runoff pollution control: State-of-the-art. A.S.C.E. Environmental Engineering Division Journal 102 (EE4): 863 (1976) and 102 (EE1): 107-125.
107. MOORE, K.W. (1978) Urban storm water management. Water and Pollution Control, Feb. 1978: 18-19.
108. DOWNING, A.L. (1972) Making Waste Water Purer Still. Information Service of the British High Commission in Australia–Feature Dec. 1972.
109. ANON. (1976) Surveying America's Lakes. Environmental Science and Technology 10 (9): 862-864.
110. HASLER, A.D. (1947) Eutrophication of Lakes by Domestic Drainage. Ecology 28: 383-395.
111. EMMELIN, L. (1974) Curing Sick Lakes. Environmental Planning in Sweden. Current Sweden 50. Swedish Institute April 1974.
112. DEPARTMENT OF CONSERVATION AND ENVIRONMENT, WESTERN AUSTRALIA (1976) Report of the Algae Odour Control Working Group.
113. WOLVERTON, B., McDONALD, R.C. (1976) Don't Waste Water-weeds. New Scientist 12: 318-320.
114. UNITED STATES SOIL CONSERVATION SERVICE. (1977). National Handbook for Conservation Practices. U.S. Govt. Print. 1977: Ch 16.
115. RUNGE, F.D. (1977) Whole Catchment Management. In: Problems of Streams and Stream Frontages, Victoria's Resources 19 (1): 15-17.
116. TURNBULL, C.K. (1977) Purpose of Stream Management. In: Problems of Streams and Stream Frontages, Victoria's Resources 19 (1): 10-12.
117. CARBON, B.A. Personal communication.
118. McCOY, C.G. (1975) Preserving Life in Murphy's Swamp. AQUA Official Journal of the State Rivers and Water Supply Commission: 15-16.
119. W.A. GOVERNMENT 1976 COUNTRY WATER SUPPLY ACT No. 81 of 1976.
120. HARLEY, K.L.S. (1977) Biological Control of Aquatic Weeds. In: The menace of water hyacinth and other aquatic weeds, Water Research Foundation of Australia Symposium, Adelaide, South Australia, 1977: 77-87.
121. FERRIGNO, F., MACNAMARA, L.G., JOBBINS, D.M. Ecological Approach for Improved Management of Coastal Meadowlands. Proceedings of the 56th Annual Meeting of the New Jersey Mosquito Extermination Association, Atlantic City, March 19-21, 1969.
122. DEPARTMENT OF CONSERVATION AND ENVIRONMENT, WESTERN AUSTRALIA (1977) Guidelines to the Conservation and Management of Wetlands in Western Australia.
123. WOOD, G. (1975) An assessment of eutrophication of Australian Inland Waters. Australian Water Resources Council Technical Paper 15. Australian Government Publishing Service, Canberra.

124. NATIONAL ACADEMY OF SCIENCES (1969) Eutrophication: Causes, Consequences, Correctives. International Symposium on Eutrophication. University of Wisconsin, Madison, 1967.
125. FENNER, F. (1979) Occurrence and Processes of Microbiological Pollution of Groundwater. Groundwater Pollution Conference Preprint Papers. Australian Water Resources Council, Department of National Development, 1979.

FURTHER READING

AUSTRALIAN WATER AND WASTEWATER ASSOCIATION (1975) Water in the Urban Environment. Australian Water and Wastewater Association Summer School, 3rd-7th February, 1975. Canberra. National Library of Australia.
BROWN, J. (1979) An Inventory of Research and Available Information on Wetlands in Western Australia. Revised from Chiffings, A.W. (1977). Department of Conservation and Environment, Western Australia, Bulletin No. 65.
DEPARTMENT OF CONSERVATION & ENVIRONMENT (1978) Procedures for Environmental Assessment of proposals in Western Australia. D.C.E. Bulletin No. 38. September 1978: 12p.
DEPARTMENT OF FISHERIES AND WILDLIFE, WESTERN AUSTRALIA (1978) Wetlands of the South-West of Western Australia, with special reference to the Busselton Area.
DUNNE, T., LEOPOLD, L.B. (1978) Water in Environmental Planning. W.H. Freeman & Co. San Francisco. 818 pp.
HODGKIN, E.P. (1974) Biological Aspects of Coastal Zone Development in Western Australia, I General Aspects. In: The Impact of Human Activities on Coastal Zones. Proceedings Australian-UNESCO Committee for Man and the Biosphere. National Symposium, Sydney, May, 1973. Publication No. 1.
HODGKIN, E.P. (1978) Blackwood River Estuary–An Environmental Study of the Blackwood River Estuary, Western Australia. 1974-75. Report No. 1, Department of Conservation and Environment, Western Australia.
HODGKIN, E.P. & MAJER, K. An Index to Ecological Information on Estuaries and Marine Embayments, C.S.I.R.O. Division of Fisheries and Oceanography Report 70, 1976.
HYNES, H.B.N. (1975) The Stream and its Valley. Edgardo Baldi Memorial Lecture. Verh. Internat. Verein. Limnol. 19: 1-15.