GUIDELINES FOR DESIGN OF EFFECTIVE BUFFERS FOR WETLANDS ON THE SWAN COASTAL PLAIN.

Peter M. Davies & J.A.K. Lane

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SUMMARY

Since European settlement, the majority of wetlands on the Swan Coastal Plain have been filled and/or drained and many of those remaining are under threat, predominantly from increasing urbanisation and intensification of agriculture. At present, inadequate buffers are considered to be responsible for the majority of wetland degradation and subsequent expenses accompanied with successful management. However, in the absence of relevant scientific information, arguments for larger buffer zones have had little influence (Lane 1991).

The majority of Australian and overseas research on effective buffer zones around wetlands has been conducted on upland streams, typically in association with timber harvest. In contrast, lentic systems (lakes, swamps *etc*) have received little attention. This is unfortunate, as these systems dominate the Swan Coastal Plain, representing over 85% of the total wetland area. In recognition of this, these guidelines are directed predominantly at lentic ecosystems. Specifically, these guidelines provide information on:

Definition of a "wetland".
Determination of a wetland boundary.
Wetland issues to consider when determining an adequate buffer zone.
Recommended criterion-based buffer zone widths.

In this present document, a fully functional wetland is considered to comprise both the open water environment and the associated wetland-dependent vegetation. This definition emphasises the ecological linkage between soil-water levels and vegetation. The wetland boundary is therefore the outer extent of the wetland-dependent vegetation. Using this wetland definition, a buffer zone is defined as an area of terrestrial vegetation which is upslope of the wetland-dependent vegetation. Previous definitions of wetlands, limited to the extent of the open water, are considered ecologically unsound by under-emphasising the functional linkage between vegetation and soil-water levels.

Adequate buffer zones perform the following functions:

Reduce water runoff from surrounding land into the wetland.
Reduce the amount of sediments, contaminants and nutrients in this runoff.
Prevent invasion of exotic plants.
Reduce disturbance of fauna by noises and/or disruptive movements (*e.g.* cars).
Obscure incompatible scenery from the wetland (*e.g.* housing).
Provide corridors for wildlife movement.
Provide a transition between upland and lowland habitats.
Provide an area between high nuisance insect numbers and residential areas.

In the determination of effective buffer zones, appropriate width is the pervasive issue. In this document, assessment of appropriate widths is extrapolated from the results of studies mainly from New Zealand and USA. The degree to which these results are "transferable" depends upon the similarities of the physical condition where these studies were conducted compared to those on the Swan Coastal Plain. The majority of Swan Coastal Plain soils (85 to 90%) are classified as sands, which have a poor ability to bind and retain nutrients and other pollutants applied to soil. Therefore, extrapolation of results from overseas studies includes recognition of the generally high permeability of soils of the Swan Coastal Plain.

Ideally, adequate buffer zones would include the entire catchment; usually not attainable in practice and due to the diverse range of threats that can impact upon a wetland, there can be no single adequate buffer zone width. In recognition of this, a criterion-based model is developed where, depending on the major threat and the main function to be protected, different buffer zone widths are recommended.

Although in this document the buffer zone is defined as terrestrial vegetation upslope of the wetland-dependent vegetation, for some threats (*e.g.* nuisance insects) the wetland-dependent vegetation will also become part of the functional buffer zone. For the setting of parameter-based buffer widths, measurements therefore need to be made from different components of the wetland depending on the major threat (*e.g.* measured from the permanent water for nuisance insect problems, and from the outer edge of wetland-dependent vegetation for nutrient inputs, as excessive nutrients will adversely affect both the wetland-dependent vegetation and the open-water habitat).

An adequate buffer zone for maintenance of ecological processes and major food-webs is recommended at 20 to 50m, measured from the outer edge of open water and will therefore include wetland-dependent vegetation. Recommended buffer zones for protection from nutrient inputs range from 100m in non-sandy soils to 200m on sandy soils, measured from the outer edge of the wetland-dependent vegetation. Excessive salinity can be a problem both to the aquatic component of a wetland and the wetland-dependent vegetation. Therefore the recommended buffer width for this parameter is 250m measured from the outer edge of the wetland-dependent vegetation. Nuisance insects, predominantly chironomids, pupate from open water and then migrate outwards from the wetland. In this case, a buffer zone from 100 to 800m is recommended, dependent on factors including the extent of the nuisance problem and wetland orientation. The recommended buffer width for minimisation of sedimentation is 100m, measured from the outer edge of the seasonally inundated zone. For protection of groundwater, a buffer of 2km is recommended, measured from the outer edge of the wetland-dependent vegetation. The recommended buffer width for minimisation of disturbance is dependent on the animal species involved. Some waterbird species, for example Eurasian Coots, appear to be little affected by disturbance whilst others, *e.g.* Freckled Ducks, may require an extensive buffer zone. The buffer zone for minimisation of disturbance is measured from the outer edge of the wetland-dependent vegetation. The input of heavy metals can adversely affect both wetland-dependent vegetation and the open-water habitat. The recommended buffer width for protection from this form of pollution is 100 to 200m measured from the outer edge of the wetland-dependent vegetation.

The buffer zone should also include a small additional area to minimise "edge effects" and to accommodate successive degradation of the buffer edge. After setting the buffer zone, adequate fencing and signage outlining intended purpose of the wetland should be a high priority to signify to adjacent residents the tenure and purpose of the land. Adequate fencing should control access to both livestock and domestic pets within the wetland system.

Environmental costs associated with inappropriate buffers include disturbance of waterbird activities, particularly nesting, modification of typical wetland food-webs, increased eutrophication, sedimentation, disruption of reproductive migrations (*e.g.* the Long-necked Tortoise) and importantly, a gradual loss of biodiversity. Economic costs include expenses associated with midge spraying, filtration of drain water, removal of invasive plant species and provision of suitable replacement land elsewhere.

Adequate buffer zones, although pivotal to successful wetland management, should be considered as only a part of integrated catchment management (ICM). In ICM, land-use practices upslope of the buffer zone need to be regulated as any zone has a limited assimilative capacity to accept pollution derived from the catchment.

With the increasing rate of development on the Swan Coastal Plain, there is an urgent need to address the buffer issue for wetlands. Arguably with the setting of adequate buffer zones, the majority of wetland management problems will be substantially reduced. Decisions regarding wetlands and their management should be made with a linked methodology of shared goals involving managers and residents ("soft approach") with a fall-back position using legislative and regulatory mechanisms ("hard approach").

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1. INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

This guide is intended for people concerned with developments on or adjacent to wetlands on the Swan Coastal Plain. Specifically, this guide provides information on:

- Definition of a "wetland".
- Determination of a wetland boundary.
- Wetland issues to consider when determining an adequate buffer zone.
- Recommended criterion-based buffer zone widths.

1.2. WETLAND DEFINITION

The Draft State Wetland Conservation Policy for Western Australia (Western Australian Government 1992) defines wetlands as "areas of permanent, or periodic inundation; whether natural or otherwise; fresh, brackish or saline; static or flowing". This definition includes lakes, swamps, marshes and dams; estuaries, rivers, streams and springs, and intertidal sand flats, mud flats and mangroves. The above definition is based on the physical, chemical and biological properties of wetlands. However, it should be noted that there can be no single ecologically sound definition of a wetland as the transition between dry and wet environments lies along a continuum (Cowardin *et al.* 1979), which is particularly true for the palusplain type wetlands (seasonally waterlogged flat) which are common on the Swan Coastal Plain (Semeniuk 1987a). The Ramsar[1] definition includes marine systems, where water depth at low tide does not exceed six metres. However, for the purposes of the present document, the definition in the Draft State Wetland Conservation Policy for Western Australia (Western Australian Government 1992) is considered more appropriate and marine systems included in the Ramsar definition are better addressed through specific marine programs and legislation.

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[1] The Ramsar Convention (Convention on Wetlands of International Importance, Especially as Waterfowl Habitat) was adopted in Ramsar, Iran, in 1971 as an intergovernmental treaty to provide a framework for international cooperation for the conservation of wetland habitats.

2. WETLANDS OF THE SWAN COASTAL PLAIN

This guide is specifically for wetlands of the Swan Coastal Plain. The extent of the Swan Coastal Plain is defined as extending from Dongara in the North to the Leeuwin-Naturaliste ridge to the South, with the easterly boundary at the foot of the Gingin, Darling and Whicher scarps (north to south respectively) and the westerly boundary at the Indian Ocean (Mulcahy & Bettenay 1972).

The Swan Coastal Plain is an area of increasing urban development and intensification of agriculture. At present, a population of over one million people reside on the Swan Coastal Plain which is resulting in increased demand for potable water supplies. Potential water supplies of the area are characterised by significant fresh and brackish groundwater resources (Webster 1989). At present, fresh groundwater supplies approximately 60% of Perth's domestic, agricultural and industrial demands (Ventriss 1989).

The Swan Coastal Plain is characterised by a high diversity of plant species, which is considered a function of differing soil types (McArthur & Bettenay 1960, Cresswell & Bridgewater 1985). Since European settlement, vegetation has been subject to; clearing, increased frequency of burning and other perturbations (Backshall 1983, Balla & Davis 1993) favouring the establishment and spread of introduced plant species. The combined effects of fire regimes and other environmental perturbations have tended to obscure vegetational boundaries. There are 49 units (plant complexes and communities) on the Swan Coastal Plain on sand deposits of marine origin and species richness of plants is greatest on the oldest dune system (Bassendean Sands) and least in the youngest dunes, the Quindalup Sands (Cresswell & Bridgewater 1985).

Lentic (still-water) wetlands, either directly or *via* food-webs, support the majority of fauna and important ecological processes on the Swan Coastal Plain (Seddon 1972). During summer, permanent wetlands are important as drought refuges for waterbirds. Although wetlands are regions of high environmental significance, approximately 70% of wetlands on the Swan Coastal Plain, representing 200,000 ha have been filled and/or drained (Riggert 1966) or drastically modified by vegetation clearing (Halse 1989). Therefore, there is a great need to conserve and successfully manage the remaining wetlands. At present, the wetlands of the Swan Coastal Plain have been mapped in detail by the Water Authority of Western Australia (Water Authority of Western Australia 1993). These maps show putative "zones of influence" around each wetland and should be considered as an initial step to the setting of adequate buffer zones on wetlands on the Swan Coastal Plain. For an inventory of past research on wetlands of the Swan Coastal Plain see Brown (1979) and Bunn & Brock (1984).

Wetlands are important functional units of the landscape and have a number of values that, individually or collectively, justify protection (Mossop 1992). These include:

Flora/fauna habitats.
Areas of scientific research and education.
Natural water drainage.
Recreation.
Aesthetic values.
Areas of high productivity.
Breeding and nursery areas for fish *etc.*
High biodiversity.
Nutrient and material cycling.
Sediment trapping.
Economic values.

The wetlands[2] of the Swan Coastal Plain have been classified on geomorphic settings (the cross sectional shape of the wetland) and the degree of water permanence (Semeniuk 1987a) (Table 1). Lotic (running water) wetlands represent < 1% of the total area occupied by wetlands on the Swan Coastal Plain (Table 2). Lentic wetlands (lakes, damplands, sumplands and palusplains, Table 1) are the dominant wetland type on the Swan Coastal Plain, representing over 85% of the total wetland area (Table 2).

Table 1. Classification of wetland systems on the Swan Coastal Plain and terminology (after Semeniuk 1987a). Permanent inundated flats and seasonally waterlogged channels are rare on the Swan Coastal Plain and, as such, are not included in the classification (Semeniuk 1987a).

WATER PERMANENCE	CROSS SECTIONAL SHAPE		
	BASIN	FLAT	CHANNEL
PERMANENTLY INUNDATED	LAKE	-	RIVER
SEASONALLY INUNDATED	SUMPLAND	FLOODPLAIN	CREEK
SEASONALLY WATERLOGGED	DAMPLAND	PALUSPLAIN	-

2 Note this classification is only for wetlands in the Wedge Island to Dunsborough region.

Table 2. The percentage of the total area occupied by different wetland types on the Swan Coastal Plain. After Semeniuk (1987a).

WETLAND TYPE	*% OF TOTAL AREA*
ARTIFICIAL BASIN	0.2
RIVER	0.6
LAKE	4.6
FLOODPLAIN	4.8
ESTUARY	7.9
SUMPLAND	10.3
DAMPLAND	12.9
PALUSPLAIN	58.8

3. WETLAND POLICY AND INTERNATIONAL OBLIGATIONS.

Wetlands of the Swan Coastal Plain are vital for many trans-equatorial migratory birds and, in recognition of their importance, several of these wetlands have been listed as wetlands of international importance under the Ramsar Convention. This status imposes international obligations on managers of the Ramsar wetlands.

Recently, the Australian Nature Conservation Agency (ANCA) produced "A Directory of Important Wetlands in Australia" (ANCA 1993). This Directory is intended to become an on-going national program where wetland inclusion is based on a standardised format.

Conservation of wetlands of the Swan Coastal Plain is covered by an Environmental Protection Authority policy (Environmental Protection Authority 1992) of conservation by reservation where:

> "An adequate and representative system of reserves should be set aside for the conservation of flora, fauna and landscape."
>
> "Such reserves should be properly managed and given security of tenure commensurate with their conservation value."
>
> "The integrity of such reserves should be maintained. Activities, both within reserves and adjacent to them, that adversely impact upon the conservation values of the reserves should not be allowed."

"Wetlands, and the function of wetland systems, should be protected from long term impacts."

"Beneficial uses of wetlands should be preserved by maintaining appropriate water quality."

"New wetlands should be constructed to compensate for wetland functions lost in the course of a project" (Environmental Protection Authority 1992).

Recently, the Swan Coastal Plain Lakes Environmental Protection Plan (Environmental Protection Authority 1993a) states that:

"Wetlands have high environmental and social values, but those values can be reduced or destroyed if wetlands are wholly or partly filled in with material, if they are mined or excavated, if they are polluted or if water is drained into or out of them".

"Since European settlement, the values of more than two-thirds of wetlands on the Swan Coastal Plain have been reduced or destroyed as a result of filling in, mining, excavation, pollution or changes in drainage, and the purpose of this policy is to protect the values of wetlands on the Swan Coastal Plain from being further reduced or destroyed any further by those activities".

"It is intended that no more filling in, mining, excavation, pollution or changes in drainage capable of reducing or destroying the values of wetlands on the Swan Coastal Plain will take place than is absolutely necessary".

These objectives, particularly those dealing with wetland values can only be successfully met by the setting and management of appropriate buffer zones (Woodfull *et al.* 1992).

3.1 EPA ASSESSMENT OF WETLANDS ON THE SWAN COASTAL PLAIN

The Environmental Protection Authority (EPA) has developed a procedure for assessing the management categories of wetlands on the Swan Coastal Plain (Bulletin 374, 1990 updated Bulletin 686, 1993b). This procedure is based on a questionnaire where wetlands are evaluated on the basis of some of their biological, geological and/or social attributes. This method of assessment has been developed as there are limited inventories of Swan Coastal Plain wetlands.

In the questionnaire, the importance of a buffer zone (in the case of the document, this was defined as an area 50m or wider from the water's edge) was manifest by the high score (10) given to this category. This score represents 25% of the total necessary to place a wetland into a Conservation/High Conservation category for permanent wetlands and 56% for episodic wetlands.

These EPA guidelines, however, are not considered applicable to lotic ecosystems (rivers, streams, channels *etc*) nor to lentic wetlands outside the Swan Coastal Plain (EPA Bulletin 686, 1993b). The revised document also recognises that the original document was inappropriate for assessing wetlands on the eastern edge of the Swan Coastal Plain (*e.g.* on the Bassendean Sands and Pinjarra Plain) (EPA Bulletin 686, 1993b).

4. ATTRIBUTES OF WETLANDS

4.1. DEFINITION OF A WETLAND BOUNDARY

Wetlands include the saturated interface of land and water and their boundaries are characterised by strong waterlogging and often salinity gradients. These gradients result in a distinct zonation of vegetation. Vegetation can therefore be useful to define wetland boundaries. A vegetation-based definition of a wetland boundary emphasises a functional approach (*e.g.* the ecological linkage between the water-body and wetland dependent vegetation) rather than the use of an arbitrary definition, *e.g.* one chain (~20m) each side of a river (Mossop 1992). A vegetation-based wetland boundary definition has been adopted in many States in the USA (*e.g.* the New Jersey *Wetlands Act* 1970) (see Nilson & Diamond 1989). A similar definition is in the New Zealand Resource Management Act (1991), where a wetland boundary is that which "supports a natural ecosystem of plants and animals that are adapted to wet conditions".

When the native vegetation adjoining wetlands has been extensively cleared, the wetland boundary is defined by seasonal extent of hydric (waterlogged) soils (Best *et al.* 1990). Failure to recognise the boundary of the wetland as being the outer limit of wetland vegetation/ hydric soils can result in a substantial underestimation of total wetland size. It also leads to fragmentation of functioning ecosystems and consequent problems associated with effective management.

The Environmental Protection Authority Bulletin 686 (1993b) suggests determining the boundary of a wetland by the use of aerial photographs and maps to identify vegetation boundaries. However, for wetlands with poorly defined vegetation boundaries, this method can be difficult. The Water Authority of Western Australia has produced detailed maps of wetlands on the Swan Coastal Plain (Water Authority of Western Australia 1993) which should be consulted as an initial step to determine wetland boundaries.

4.2 WETLAND PLANT SPECIES

A number of species are appropriate to define wetland boundaries (Appendix I). The *Melaleuca* species are valuable wetland boundary species particularly *M. cuticularis* and *M. rhaphiophylla.* However, some subjective assessment may be required with some species *e. g. Eucalyptus rudis* which may grow in other, non-wetland habitats probably reflecting a previous, wetter phase. Species very common to palusplains, *e.g. Hypocalymma angustifolium* and *Kunzea ericifolia* (Spearwood) also occur in dry land regions and may not be reliable indicators of a wetland boundary. Annuals are considered of less importance due to difficulties associated with identification when they are not in flower. Similarly, disturbance species (*e.g.* the Coastal Wattle; *Acacia saligna*) may not be useful to determine the accurate boundary of a wetland. There have been several studies on the dominant wetland plant species and zonations for systems on the Swan Coastal Plain Cresswell & Bridgewater 1985, Semeniuk *et al.* 1990, Froend *et al.* 1993).

Tiner (1991) assessed a statistical approach to define the position of a wetland boundary based on wetland dependent vegetation. An area is defined as a functional wetland if the majority of the dominant plant species are obligate wetland (must be associated with a wetland) or facultative wetland species (increased frequency adjacent to wetlands). This method is yet to be used for wetlands of the Swan Coastal Plain.

4.3 FAUNA ASSOCIATED WITH WETLAND VEGETATION.

As yet, there have been few detailed surveys of the fauna of remnant vegetation adjacent to wetlands on the Swan Coastal Plain. The results from these studies show these regions to be highly biodiverse.

Areas adjacent to the surface water in wetlands include fauna such as the Southern Brown Bandicoot (*Isoodon obesulus*) which is classified "rare and endangered" (Government Gazette 1990). The favoured habitat of this species is an understorey of sedge, with an overstorey of trees. The Native Water-rat *Hydromys chrysogaster* is restricted to riparian and adjacent upland vegetation (Western Australian Museum 1978). Eight species of frogs are found adjacent to wetlands on the Swan Coastal Plain (Godfrey 1989, Godfrey *et al.* 1992). Apart from zoos, the Short-necked Tortoise (*Pseudemydura umbrina*) is now restricted to only one small wetland on the northern Swan Coastal Plain. *Lerista lineata,* a burrowing species of skink, is usually found adjacent to wetlands (Storr *et al.* 1981) and was initially described as a species "rare or in special need of protection". Wetlands of the Busselton area contain high numbers of Grey Kangaroo, Ringtail and Brushtail Possums and the Bush Rat (C. Broadbent, Department of CALM; pers comm). The Long-necked Tortoise and tiger snakes are common to many wetlands on the Swan Coastal Plain. The terrestrial species are either upland species utilising wetland dependent vegetation or wetland fauna utilising adjacent upland vegetation. Specific studies are required to determine actual levels of dependence of terrestrial fauna on different components of the wetland and adjacent vegetation.

Elsewhere, wetlands have been shown to support the greatest concentration of bird species (New Zealand; Buxton 1991). In New Zealand, wetlands represent about 2% of the land area but are used by 22% of birds as their primary habitat, with a further 5% of species using wetlands as an important secondary habitat (Buxton 1991).

4.4 ECOTONES

Ecotones are areas of change in ecological and biological characteristics typified by rapidly changing vegetation. Ecotones are recognised as biological "hotspots" (Risser 1990). Generally buffer zones and wetland-dependent vegetation would include ecotones between terrestrial and aquatic ecosystems (Riding & Carter 1992). Ecotones are typically biodiverse as they may contain communities of one or both systems (Riding & Carter 1992) due to proximate and functional linkages with adjacent ecosystems (Risser 1990). The environmental significance of remnant vegetation is generally determined by the quality and/or the rarity of a monotypic stand (*e.g.* a representative stand of Jarrah) or a particular species assemblage. This method of assessment is unlikely to consider the value of ecotones. Much previous research and assessment of the environmental quality of regions has only considered processes in a relatively homogeneous landscape (Holland & Risser 1991). A resurgence of interest has highlighted the value of boundaries between landscapes (ecotones) as areas of high biological diversity. Ecotones typically have species of the boundary landscape and organisms unique to the ecotone itself (Odum 1971). Ecotones have also been highlighted as highly susceptible regions to climatic differences, where early effects of climate change may be evaluated (Gosz 1991).

5. BUFFER ZONES

5.1 DEFINITION OF A BUFFER ZONE

Buffer zones have been generally described as areas of undeveloped vegetated land extending from the banks or high water level of a wetland to some point landward (Palfrey & Bradley undated). However, this definition and essentially many wetland definitions are considered inadequate for the wetlands of the Swan Coastal Plain. An adequate wetland definition should include wetland dependent vegetation as an integral part of the wetland ecosystem.

For the basis of this document, a buffer zone is described as an area of terrestrial vegetation that is upslope of the outer edge of wetland-dependent vegetation. This definition recognises the functional linkage between the type of vegetation and soil-water levels.

Figure 1 shows the extent of the wetland and the inner boundary of a buffer zone. The seasonally inundated region is characterised by emergent vegetation including species such as *Baumea articulata*. The wetland dependent vegetation (part of the wetland) is typified by *Melaleuca* species including *M. preissiana*. The buffer zone is characterised by *Eucalyptus* species including *E. marginata* (Jarrah) *E. calophylla* (Marri), *E. gomphocephala* (Tuart) and in many regions *E. rudis* (Flooded Gum).

5.2 FUNCTION OF BUFFER ZONES

The function of a buffer zone is to protect a wetland from negative impacts of catchment land-uses and activities within buffer zones should not detract from their usefulness and/or performance as buffers (*e.g.* Pinder *et al.* 1991). Buffer zones are important transition areas, with a variety of soil and hydrology, reflected by rapidly changing flora. It should be emphasised, however, that buffer zones, as outlined in this document, emphasise surface flow into wetlands. Buffer zones for the protection of groundwater-fed wetlands need to be incorporated in an overall catchment management strategy.

In the absence of a buffer zone, a wetland is vulnerable to impacts and even with low level impacts, the outer edge of the wetland may lose its inherent "wetland value" and, as such, serve only as a "buffer zone" to a smaller inner core, diminishing the effective size of the wetland (Buxton 1991).

Buffer zones need to perform the following functions (after Buxton 1991):

Reduce water runoff from surrounding land.
Reduce the amount of sediments, contaminants and nutrients in this runoff.
Prevent invasion of exotic plants.
Reduce disturbance of fauna by noises and/or disruptive movements (*e.g.* cars).
Obscure incompatible scenery from the wetland (*e.g.* housing).
Control stream salinity.
Provide corridors for wildlife movement.
Provide a transition between upland and lowland habitats.
Provide an "barrier" between the sites of high midge numbers and residential areas.

The following additional attributes of buffer zones are more applicable for lotic (streams/rivers) wetlands (*e.g.* Ormerod *et al.* 1993):

Stabilisation of the stream/river bank by plant roots and/or rhizomes.
Reduction of the erosive capacity of water flow by vegetation.
Control of nutrient inputs.

To define an appropriate buffer zone, the following questions should be addressed (after Barling & Moore 1992):

(1) What are the major wetland functions?
(2) What variety of controls could the buffer zone fulfil and how will the size of the zone affect these controls?
(3) Where and how often will the buffer zone fulfil its design function?

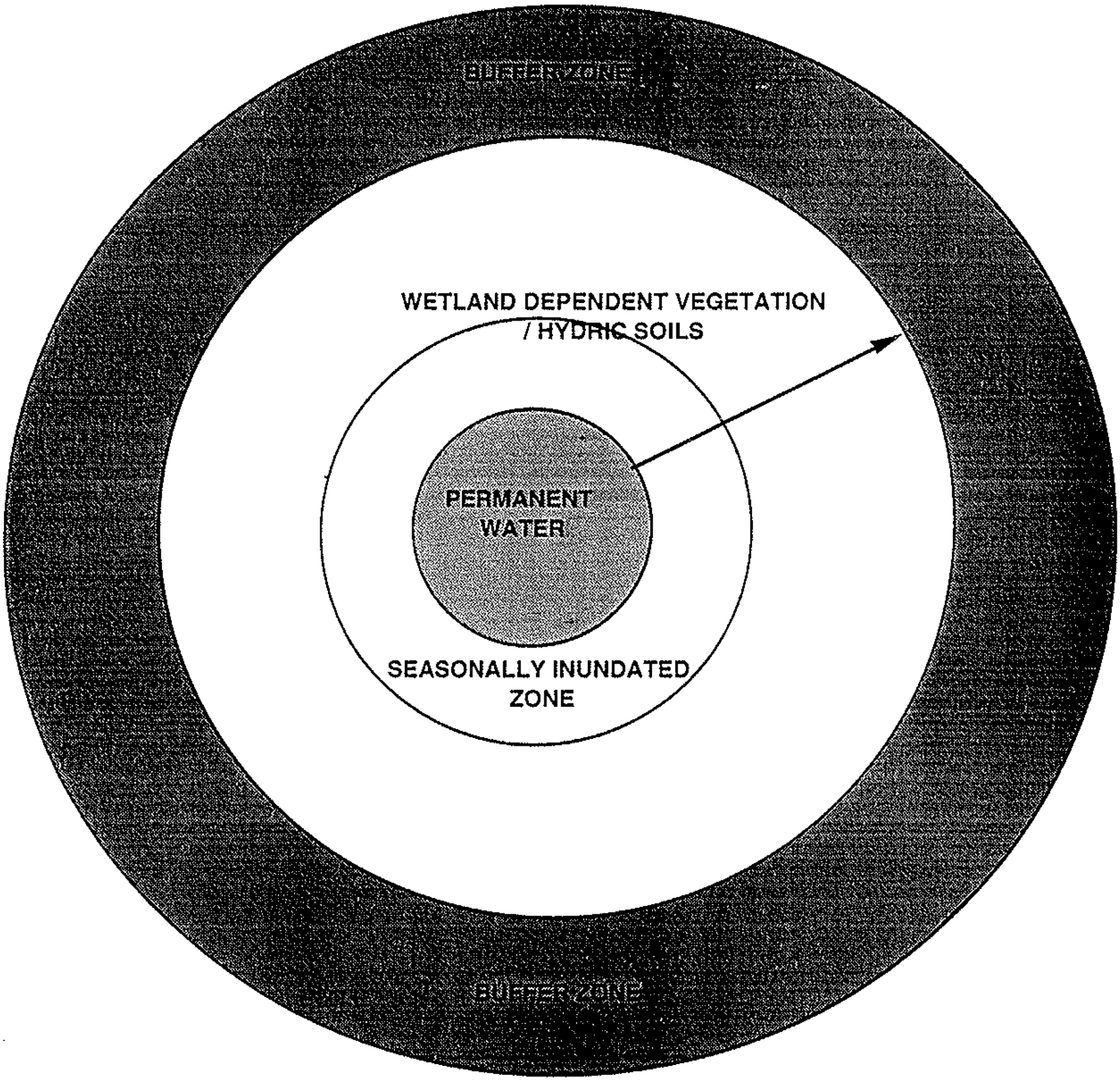

Figure 1. The definition of a wetland based on the upslope extent of the wetland dependent vegetation. The buffer zone is therefore upslope of the wetland dependent vegetation. Figure modified after Semeniuk & Semeniuk (in press).

5.3 BUFFER ZONES AS REMNANT VEGETATION

Buffer zones, as well as providing "protection" to a wetland, can be considered remnant vegetation in their own right. Remnant vegetation is either a remainder of the natural vegetation of the land or, if altered, is still representative of the structure or floristics of natural vegetation. On the Swan Coastal Plain, remnants of native vegetation have high conservation value as habitat for fauna as much of the Plain has been cleared.

Remnant vegetation adjacent to open water often has increased habitat value compared to remnant vegetation elsewhere, and due to rapidly changing soil moisture conditions, remnant vegetation adjacent to wetlands is characterised by a number of ecotones.

5.4 PRESCRIBED BUFFER ZONE WIDTHS IN OTHER REGIONS

Research on what constitutes an adequate buffer width has been conducted on streams and rivers, predominantly in the USA. In the Placer County, California (Palfrey & Bradley undated), the width of an appropriate buffer zone on streams and rivers was determined on a case-by case basis that included a consideration of:

(1) Soil types and how far the surface water infiltrates the soil.
(2) Types and amount of vegetation and how effective it is in stabilising the ground.
(3) The slope of the land and how significant it is for sediment retention.

In Fairfax County, Virginia, a minimum buffer width was set at 50 feet + (4 x per cent of slope) (Palfrey & Bradley undated) for streams and rivers. In addition to this specified area, adequate buffer zones incorporated:

(1) 100 year floodplains.
(2) Floodplain soils (*i.e.* high water table, poor bearing strength, or other development constraints).
(3) Steep slopes (>15%) above the floodplains.

The New Jersey Department of Environmental Protection in a "New Jersey Coastal Resource and Development Wetlands Buffer Policy" (1970) (cited in Nilson & Diamond 1989) states:

> "All land within 100m of wetlands (defined in NJ AC 7: 7E- 3.26) and within the drainage (*i.e.* catchment area) of those wetlands comprise an area within which the needs for a wetland buffer shall be determined".

This policy is applied on a case by case basis. Development is approved when determined likely to cause minimal impact on both the wetlands and on the natural ecotone between wetlands and surrounding land.

The California Coastal Commission in it's "Statewide Interpretive Guidelines for Wetlands and Other Wet Environmentally Sensitive Habitat Areas" (1979) sets a minimum buffer width of 100 feet (~30m), with the width increasing dependent on the following criteria; biological significance, sensitivity of wildlife in the buffer zone, susceptibility to erosion, and development criteria including scale and position. The basis of these Californian recommendations are similar to those in this document, where a criterion-based system is suggested, where adequate buffer widths depend on the nature of activities in the catchment.

In a review, Palfrey & Bradley (undated) prescribe a minimal buffer width of 30m from the mean high-water line where zones should be large enough to include; 100 year floodplain, tidal areas, steep slopes and areas with development constraints. For adjacent sloping land (*e.g.* >5%), a substantial amount of the steep area should be included into the buffer zone.

In most of these cases from the United States, the greater the slope, the wider the specified buffer zone. This is primarily due to the emphasis of the research on buffer zones in the USA, which is generally directed at logged stream catchments. In these conditions, the slope of the catchment is an important determinant of the amount of sediment that is transported into the streams.

In Victoria, Australia, buffer zones are used to maintain soil conservation in stream catchments. Buffer width follows the formula defined by Trimble and Sartz (1957), where W=width of the buffer strip in metres and S=slope (percentage):

$$W=8 + 0.6 (S)$$

The majority of overseas research on effective buffer zones have prescribed the width of a buffer zone of riparian vegetation necessary to minimise sedimentation in streams in timber production areas (Anon. 1992). The main timber production areas in the south-west of Western Australia are outside the boundaries of the Swan Coastal Plain and therefore not considered in this document.

5.5 EXISTING BUFFERS ON WETLANDS ON THE SWAN COASTAL PLAIN.

There are few examples of adequate buffer zones on wetlands of the Swan Coastal Plain. However some good examples of an adequate buffer zone include the Leda Wetlands and Lake Mt Brown (P. Jennings pers comm); in these examples the management of the wetlands has been made on a whole catchment basis. Another good example of the determination of wetland and buffer boundaries was provided by the EPA when planning an adequate buffer associated with a residential development at Frenchman Bay, Albany (EPA 1993c).

Although this area is outside the Swan Coastal Plain, the vegetation is similar and the wetland issues are directly relevant to this document. Lake Vancouver is defined as a wetland of high conservation value (EPA 1993c) and therefore provision of an adequate buffer zone was important for wetland protection in the context of increasing development within the catchment.

The Environmental Protection Authority defined the boundary of the Lake by the extent of wetland dependent vegetation, which in the case of Lake Vancouver was the *Melaleuca cuticularis/ Banksia littoralis* species distribution. They described the physical buffer as an area of native dryland vegetation defined by *Agonis flexuosa/Adenanthos sericeus* closed scrub. In this case, the buffer zone was designed for:

(1) separation of the water habitat from human activities and
(2) provision of a complementary habitat for wildlife using the wetland.

The width of the vegetated area from the water's edge to development was set at 50-100m. Parts of the nominated buffer zone were privately owned and, as a consequence, restrictions on activities were considered appropriate.

Bad examples of buffer zone management on the Swan Coastal Plain include regions such as Salter's Point which originally had a substantial vegetated buffer until sub-divisions in the 1950's (Crowley 1962). With clearing, compensation effects and landfill, nutrient inputs resulted in mosquito and midge problems and localised flooding during the wetter years.

5.6 TRANSFERABILITY OF OVERSEAS RESULTS

The setting of adequate buffer zones on Swan Coastal Plain wetlands is based predominantly on the results of overseas research. This is due to the lack of suitable research on this issue on wetlands of the Swan Coastal Plain. However, the application of research conducted elsewhere to the wetlands of the Swan Coastal Plain requires some allowance to be made for the unique characteristics of Swan Coastal Plain soils. A total of 85 to 90% of these soils are classified as sands with a poor ability to bind and retain nutrients and other pollutants applied to soil (George 1989). They are therefore, highly permeable to salinity intrusion and nutrient transport. Extrapolation of the results from overseas research must therefore take into account the high permeability of typical Swan Coastal Plain soils. This necessitates an increase in the minimum recommended buffer zone widths. It should be noted that overseas and Australian research on buffer zones has considered the extent of the surface water as the wetland boundary. In contrast, this guide considers the maximum upslope extent of the wetland dependent vegetation and/or hydric soils as the wetland boundary.

Table 3. Buffer/ riparian widths and the associated management issue in a number of studies. Widths are given in increasing sizes.

BUFFER WIDTH (metres)	HABITAT (REGION)	MANAGEMENT ISSUES	REFERENCE
20	Wetlands (NZ)	Flat-land	Buxton (1991)
20-30	streams	Timber harvesting	Hesser (1975)
20-40	Streams	Clear-felling	Dept of Agriculture and Fisheries NSW (1991)
30		All land use types	Dept of Agriculture and Fisheries NSW (1991)
30	Streams	Gross levels of bacteria	McNeill (1992)
35	Wetlands (NZ)	1: 10 slope	Buxton (1991)
40	rivers	Clear-felling	Dept of Agriculture and Fisheries NSW (1991)
40 (from highlines)	Riverine sites	Disturbance of roosting sites	Armbruster & Farmer (1981)
40 (from private roads)	Riverine sites	Disturbance of roosting sites	Armbruster & Farmer (1981)
40-50	wetlands	Ground nesting waterbirds	Lane (1991)
50	Streams (SWA[3])		Borg *et al.* (1987)
50	Wetlands (NZ)	1: 5 slope	Buxton (1991)
>50	Wetlands	Water-birds	Halse (1991)
50-200	Wetlands (WA)		Hill (1992)
50-200	Basin, channel and flat wetlands		DPUD Townscape Manual (1992)
65	Wetlands (NZ)	1: 3 slope	Buxton (1991)
100 (50m each side)	Creeks (WA)		Hill (1992)
100	Estuaries	Nitrogen pollution	Buxton (1991)
100	Rivers (SWA)	Sedimentation, salinity	Borg *et al.* (1987) Growns *et al.* (1992)
100	Streams (SWA)	Forest logging	Forestry Dept (1973)
100	Wetlands (USA)	Nutrient loading	Palfrey & Bradley
100	Watercourses	Pollution seepage	Leopold (1968)
100-500	Urbanised wetlands	Environmental significance	Semeniuk & Semeniuk (1992)
160	Moors (UK)	Herbicide drift	Marrs *et al.* (1992)
200	Perennial streams (USA)	"Protection" of Chesapeake Bay	Liebmann (1992)
200 (from gravel road)	Riverine sites	Disturbance of roosting sites	Armbruster & Farmer (1981)
200 (from recreational area)	Riverine sites	Disturbance of roosting sites	Armbruster & Farmer (1981)
400 (from bridges)	Riverine sites	Disturbance of roosting sites	Armbruster & Farmer (1981)
400 (from paved road)	Riverine sites	Disturbance of roosting sites	Armbruster & Farmer (1981)
400 (from railway)	Riverine sites	Disturbance of roosting sites	Armbruster & Farmer (1981)
400 (from single dwelling)	Riverine sites	Disturbance of roosting sites	Armbruster & Farmer (1981)
800 (from commercial development)	Riverine sites	Disturbance of roosting sites	Armbruster & Farmer (1981)

[3] South-western Australia.

Table 3 (cont.). Buffer/ riparian widths and the associated management issue in a number of studies.

800 (from urban dwellings)	Riverine sites	Disturbance of roosting sites	Armbruster & Farmer (1981)
800	Wetlands	Midge problems	Pinder *et al.* (1991)
1000	Wetlands	Disturbance	Buxton (1991)
1000	Wetlands	Midge problems	City of Cockburn (cited in Lane 1991)
2000	Groundwater	Maintenance of water quality	Van Waegeningh (1981)

6. CRITERIA FOR ESTABLISHING BUFFER WIDTHS

6.1 INTRODUCTION

When a development impinges on a wetland, the initial decision is the appropriate width of the buffer zone. Ideally, a buffer zone or "setback" should include the entire surface water catchment and the groundwater catchment of the wetland (Van Waegeningh 1981). However, in practice this is rarely attainable. Many wetlands of the Swan Coastal Plain are characterised by very small buffer zones, typically no more than 10-20 metres wide and in the absence of scientific information, arguments for larger buffer zones have had little influence (Lane 1991). In fact, in many cases, the so-called buffer zone is little more than the fringing emergent vegetation, which is an integral component of the wetland itself.

The adequacy of a buffer zone is dependent on its intended function and a number of buffer zone issues need to be considered when determining the width of an adequate buffer zone. This is a criterion-specific approach where the function of the wetland is emphasised. Listed below in points 6.1 to 6.12 are individual issues necessary to consider when devising an adequate criterion-based buffer zone. However, it should be noted that in many instances, a buffer zone will need to provide protection to a wetland from a variety, rather than from a single threat. In these cases, the maximum width recommended is appropriate for an adequate buffer zone. Buffer zones should extend on tributaries, and where possible, link together throughout the catchment.

6.2. CARBON FLOW THROUGH FOOD-WEBS

Lentic wetlands are characterised by two, interconnected food webs; a system based on primary production and a terrestrial detritus-based web. Terrestrial material that falls or is washed into the wetland is an important source of carbon for many benthic macroinvertebrate species (Davies 1994). Terrestrial insects that fall into streams and rivers form a major component of the diet of the most common fish species in the south-west of Western Australia including the Native Minnow *Galaxias occidentalis* (Pen & Potter 1991). Woody material (*e.g.* logs, branches, bark *etc*) that falls into streams and rivers also offers fish and macroinvertebrates shelter from increased water discharge and the structural habitat formed by woody material is important in some regions as spawning areas (Parson 1991). On the basis of the estimated rates of consumption of terrestrial detrital material by the fauna in upland streams in the Northern Jarrah Forest (Davies 1993, 1994), it has been estimated that a 20 to 50m buffer of dense vegetation would be adequate to supply sufficient detritus to "drive" ecological processes associated with detrital material. In the absence of similar studies in lentic systems, this value is considered appropriate to lentic systems on the Swan Coastal Plain.

6.3. NUTRIENTS

The major cause of eutrophication (nutrient over-enrichment) of Swan Coastal Plain wetlands is transport of nutrients from fertilised agricultural lands, unsewered urban areas, golf courses, gardens *etc* by surface runoff and/or groundwater discharge. Although nutrients are natural components of a functional wetland ecosystem essential for biological processes (*e.g.* algae and macrophyte growth), excessive inputs of nutrients result in many water quality problems. These include algal blooms and associated problems with noxious odours, toxic by-products, smothering of the wetland substrate and anoxia. Anoxia results in the death of fish and invertebrates and causes the release of further nutrients and heavy metals (*e.g.* iron and manganese; Fischer *et al.* 1979, McFie 1973, Tyler 1980) from the sediments. Release of nutrients from the sediments can result in secondary algal blooms.

The following factors contribute to the high degree of eutrophication that occurs in many wetlands (after Birch 1984, Yeates *et al.* 1985, Schofield *et al.* 1985, Sanders *et al.* 1988, Humphries & Bott 1988, Environmental Protection Authority 1989):

The limited nutrient-holding capacity of the sandy Swan Coastal Plain soils.
A high and seasonal rainfall.
The shallow watertable.
Extensive drainage of waterlogged soils.
Over-use of fertilisers.
Inadequate treatment of effluent.
In-appropriate drains into wetlands.

A study on nutrient transport in the USA, showed that the majority of the nitrogen (88%) and phosphorus (96%) in surface runoff from agricultural land was attached to sediment particles (Palfrey & Bradley undated). The movement of nutrients through buffer zones has been investigated in a number of stream systems, however very few generalisations on nutrient movement have been derived or further evaluated. If a drain runs through the buffer zone, then the effectiveness of the zone would be minimised. This has been shown by the degraded water quality of some Cockburn wetlands in Western Australia (Schulz 1989).

Forest and grass vegetated buffer zones have been tested for their ability to reduce surface runoff polluted with manure (Doyle *et al.* 1977, Overcash *et al.* 1981). This study showed that both the grass and forested buffer zones substantially reduced the concentration of total nitrogen and phosphorus within the first few metres. For example, the concentration of total soluble phosphorus was reduced by 62% in a grass buffer that was four metres wide. Similar results have been found for Western Australian systems for management of dairy waste (Masters 1991).

In an extensive review, Palfrey and Bradley (undated) determined that, for areas of high nutrient loadings in Maryland USA, a buffer width of 100m was necessary to ensure the preservation of water quality. For septic systems, a minimum distance of 50m from the wetland was considered adequate; this distance however, is dependent on soil types.

Drains into wetlands effectively "short-circuit" any buffer zone and allow nutrients to rapidly enter without the ameliorating effects of the buffer zone (Peterjohn & Correll 1984). In these cases, the control of water quality entering a wetland would need to be considered in an overall drainage management strategy.

Eutrophication is one of the main threats to wetlands on the Swan Coastal Plain. However existing buffer widths to minimise this threat are probably generally less than North American and New Zealand counterparts. The soil types, and to a lesser extent the climate of the Swan Coastal Plain would require the setting of wider buffer zones. This, however, has not happened which is evidenced by the large number of Swan Coastal Plain wetlands that are becoming increasingly eutrophic (*e.g.* North Lake, Bibra Lake and Lake Monger).

To extrapolate the results from studies elsewhere and to be conservative, buffer widths for wetlands on sandy soils on the Swan Coastal Plain are recommended to be set at 200m *i.e.* double the 100m width Palfrey and Bradley (undated) recommended for areas of high nutrient loadings in Maryland, USA. For non-sandy soils on the Swan Coastal Plain, a buffer width of 100m is recommended.

6.4 SALINITY

Buffer zones are important for the control of salinity in areas where salinised groundwater is close to the wetland (Borg *et al.* 1987). The degradation of the water quality and the recreation and conservation value of Lake Towerrinning (near Darkin, Western Australia) is attributed to clearing of the catchment of the Lake. It is estimated that about 90% of the catchment has been cleared, resulting in a narrow peripheral band of vegetation generally 100-400m wide, although in some areas the band is absent (Froend & McComb 1991). This extensive clearing has led to both increased flooding/salinisation of the Lake and the decline of the recruitment of fringing vegetation (Froend & McComb 1991).

The extensive clearing of the upper Avon catchment included the removal of the original deep-rooted *Eucalyptus-Acacia* woodland and replacement with shallow-rooted seasonal plants. This has raised the water table, resulting in salinisation of this river system (Mulcahy 1973). With increased salinity in the Avon, many aquatic species, particularly members of the Mollusca, have become locally extinct (Kendrick 1976).

In upland streams of the Karri forest, Growns (1992) showed that streams with a 100m buffer zone did not exhibit the increases in salinity typically found in timber production areas where smaller buffer zones (usually 30m) had been left:

Salinisation of wetlands is a greater problem in systems east of the Darling Scarp (*e.g.* Taarblin Lake) or in river systems with headwaters east of the Scarp (*e.g.* the Blackwood, Murray and Avon rivers), than in systems on the Swan Coastal Plain.

6.5 SEDIMENT TRAPPING

Vegetated buffers reduce sediment generation (*i.e.* the amount of sediment released into suspension by the impact of raindrops on the ground), sediment transport and therefore sediment deposition (Carter 1992). In the United States, sediment is considered the largest single pollutant (by weight) of wetlands. In these systems, high levels of sedimentation cause detrimental effects on plants, invertebrates and vertebrate communities (Palfrey & Bradley undated). Sediment also reduces water clarity and therefore the feeding efficiency of visual predators including both fish and waterbirds.

Salmon populations in the West Coast of USA have plummeted during recent years, predominantly due to sedimentation caused by logging activities (Mestel 1993). Without adequate buffers, and/or with inadequately designed or constructed stream crossings, logging results in siltation of the stream-bed (Mestel 1993) smothering both spawning grounds and eggs preventing the emergence of hatched fry (Palfrey & Bradley undated). In studies in Maryland in USA, a 2mm layer of sediment was sufficient to cause 100% mortality in White Perch eggs and 0.5- 1mm caused in excess of 50% mortality (Palfrey & Bradley undated). The camouflaging effect of dappled shade caused by riparian vegetation can also reduce predation on fish (Koehn & O'Connor 1990). In addition to sedimentation, turbidity in excess of 100ppm greatly inhibits fish growth and reproduction (Palfrey & Bradley undated).

In a series of experiments on sedimentation in streams in Alberta, USA, stream banks with vegetation were substantially more resistant to erosion than comparable banks without vegetation (Smith 1976). In an experiment in Maryland USA, 50m of stream riparian vegetation was sufficient to reduce sediment transport by 90% (Wong & McCuen 1981).

In lotic systems, the removal of riparian vegetation results in increased erosion of the bank and during peak flows this erosion may result in sedimentation of the channel. The Avon River in Western Australia is considered to be substantially sedimented due to the almost complete clearing of native vegetation from the catchment (Kendrick 1976). High levels of sedimentation reduced the River's discharge capacity resulting in flooding. This led to the expensive and arguably ineffectual "Avon River Training Scheme" (Kendrick 1976), where the sediment and vegetation were mechanically removed from the main channel of the river.

For further information on the effect of buffer zones on stream sedimentation in Western Australia see Batini *et al.* (1980) and Clinnick (1985) and for elsewhere in Australia see Campbell (1986), Campbell and Doeg (1989) and Doeg and Koehn (1990a, 1990b).

6.6 CHANGING WATER LEVELS

Buffer widths are usually defined prior to, or at the time of, the approval of a development. Typically some developments result in increased clearing and therefore increased runoff. This may flood the fringing vegetation effectively reducing the size of a buffer zone. This flooded vegetation dies and, under natural conditions, a new zone of vegetation establishes on the upslope areas (Lane 1991).

Flooding of local wetlands has generally followed the residential development of the Perth Metropolitan Region due to increases in groundwater levels (Hedgecock & Moritz 1989). Increases in the water level of Butler's Swamp (Lake Claremont) from 1929 to 1950, despite fluctuation due to yearly differences in rainfall, were attributed to the clearing of the catchment (Evans & Sherlock 1950), a similar situation to that which occurred in Herdsman Lake (Bekle 1981). However, water levels within wetlands may be reduced by the drier conditions experienced by the Swan Coastal Plain since the late 1960's (Heddle *et al.* 1980).

Other predicted increases in water levels are associated with climatic changes due to a "greenhouse effect". Buffer zones therefore need to be wide enough to accommodate the effects of climate change resulting in rising sea-levels and upslope migration of wetlands and therefore wetland boundaries (Mossop 1992). Current predictions are of a sea-level rise of between 0.2 to 1.4m during the next 50 years (Australian Marine Sciences Association 1990) which will affect estuarine wetlands. In the Peel-Harvey Estuary, increased water levels due to marine incursion would require an increase in the size of the Nature Reserves in the south-east to allow for the upslope migration of water levels. The provision of an adequate buffer to allow for increased sea-levels, requires the measurement of land contours (*e.g.* a vertical component) to determine the horizontal extent of the zone.

In contrast to these above effects, groundwater abstraction leads to a decrease in water levels. Abstraction of groundwater in the Swan Coastal Plain has increased substantially in association with increased urban population. Abstraction appears to produce localised rather than widespread effects (Froend *et al.* 1993) and does not effect all wetlands equally. A lowering of the water table tends to result in a systematic "movement" of vegetation down the gradient (Froend *et al.* 1993).

6.7 GROUNDWATER PROTECTION

A groundwater buffer zone is a sub-surface area which is required to maintain quality of the water in the aquifer, prior to discharge of this water into a wetland. Although the vegetation on the surface of this groundwater buffer zone is of reduced direct importance for the maintenance of water quality, roots of these plants penetrate the aquifer taking up nutrients. This uptake of nutrients can enhance the quality of the groundwater. The adequacy of groundwater buffer zones is typically based on the hydrological properties of the aquifer. For many wetlands of the Swan Coastal Plain, groundwater abstraction is a major management issue, particularly wetlands associated with the Gnangara and Jandakot mounds (Lowe 1989, Davis *et al.* 1991a, 1991b).

The most important distinction in determining the adequacy of a groundwater buffer is between mostly unconsolidated and fissured (consolidated) aquifers (Van Waegeningh 1981). These two types of aquifers modify the flow velocity of the groundwater. The velocity of flow is important as generally the greater the residence time the water has in a groundwater buffer zone, the higher the water quality. Therefore, for an adequate groundwater buffer zone, the residence time of water in the aquifer is of more importance than the size of the groundwater buffer zone. The permeable soils of the Swan Coastal Plain result in short residence times for water in the aquifer. Therefore for an adequate groundwater buffer zone for pollution control, particularly in the sandy soils on the Swan Coastal Plain, an extensive area is required. In consideration of the findings of Van Waegeningh (1981), an adequate groundwater buffer zone for wetlands on the Swan Coastal Plain is up to 2000m.

6.8 NUISANCE INSECTS

The problem of pest species, particularly adult chironomids (non-biting midges) and mosquitoes has been shown to be associated with a number of wetlands on the Swan Coastal Plain (Pinder *et al.* 1991). The problem is considered to be due, at least partly, to excessive nutrient inputs which support a large phytoplankton biomass on which the chironomid larvae feed. With inadequate buffers, the adult midges and mosquitoes pose a nuisance problem to local residents. Adult midges are passive fliers, dependent on prevailing winds, and therefore dense fringing vegetation has a capacity to act as a barrier between the emergence of the adults from the wetland to nearby houses (Lane 1991). A vegetated buffer zone also screens residential lighting, an attractant to adult midges. Additionally, the buffer zone provides a habitat for predators of midges including dragonflies and web-building spiders.

Buffer zone widths sufficient to minimise midge problems have been recommended at 800m (Pinder *et al.* 1991); a distance over which the dense vegetation of the buffer zone would reduce the intensity of the nuisance. The direction of the prevailing winds can affect the level of nuisance caused by the midges. Both the prevailing south-westerly winds and the easterly winds have extended the effect of the midge problems. Further studies on the midge problems highlighted the need to reduce nutrient inputs into wetlands and the need for fringing vegetation to act as natural nutrient filters (Davis *et al.* 1987, Davis *et al.* 1988). The replanting of vegetation around lakes was an option given a high priority.

Removal of fringing vegetation in urban settings typically results in increased nutrient input into wetlands, increasing midge problems that are further exacerbated by the lack of filtering buffer zones. Midge problems are rare in wetlands that are not nutrient-enriched where there is existing fringing vegetation (Pinder *et al.* 1991). Examples of systems on the Swan Coastal Plain where chironomids cause a nuisance include Lake Joondalup, Lake Monger, Yangebup Lake and North Lake.

Mosquitoes (Culicidae) are other nuisance species and a disease-carrying vector. Their numbers appear to be elevated in wetlands where livestock has access. Livestock hooves result in indentations that, when filled with water, represent an ideal habitat for mosquito larvae. The increasing number of people effected by the mosquito-borne Ross River Virus is a concern. Associated with this, local authorities will probably apply pressure for the application of larvicides which may indirectly have an adverse effect on waterbirds. Given the public risk of Ross River Virus, buffer zones may need to be wider in wetlands where suitable mosquito habitats are inundated when conditions are favourable for mosquito development (*e.g.* during periods of high water temperatures).

6.9 DISTURBANCE

A buffer zone sufficient to minimise disturbance to waterbird activities is defined as an area of either wetland dependent and/or upland vegetation that physically separates a type of disturbance (*e.g.* roads, housing, commercial development, power lines *etc*) from normal feeding, roosting and other activities of waterbird species. Waterbirds are generally wary, seeking refuge from all forms of disturbance, particularly those associated with loud noises and/or rapid movements (Korschgen & Dahlgren 1992). The disturbances that displace waterbirds result in increased energetic costs associated with flight and therefore may reduce the productivity of nesting and/or brooding waterbirds. In extreme cases, disturbance results in the abandonment of nests (Korschgen & Dahlgren 1992).

The type of buffer required to minimise disturbance is therefore fundamentally different from a zone designed to minimise threats to a wetland ecosystem. The width of a buffer zone to minimise disturbance is a radius around a single point (*e.g.* a nesting site). The provision of adequate buffer areas, however, will be species-specific requiring detailed knowledge of individual species' requirements.

The characteristic low diversity of waterbirds on wetlands on the Swan Coastal Plain adjacent to high levels of disturbance is considered partly a function of noise and activity (Lane 1991). However, some species may become more tolerant to disturbance, including Pacific Black Duck, Eurasian Coots and Black Swans (Storey *et al.* 1993). Other disturbances within the wetlands are more disruptive including trail bikes, off-road vehicles and domestic pets. These disturbances are often within nesting areas, which would substantially reduce the effectiveness of any buffer area.

In the USA, Armbruster and Farmer (1981) have recommended disturbance buffer zones of different widths, depending on both the types of disturbance and the type of waterbird activity. To minimise the effects of human disturbance to Sandhill Crane (*Grus canadensis*) roosting sites, a 200m buffer zone was recommended from gravel roads and/or recreational areas and 400m to minimise disturbance of roosting sites from either bridges, paved roads, railways or single dwellings. The width of this buffer is increased to 800m to minimise disturbance to roost sites from commercial developments and urban dwellings. They considered power-lines a disturbance and recommended a "buffer" of at least 40m. Power-lines also represent a cause of mortality of adult birds, particularly when situated on flight paths (Perrins & Sears 1991).

The power lines adjacent to North Lake were found to be in the direct flight-path of black swans. This was particularly a problem at dusk, to the extent where beacons were installed on the wires.

Ground-nesting waterbirds

Most species of ducks nest on, or near, the ground when conditions are suitable. The Australian Shoveler (*Anas rhynchotis*) is an obligate ground nesting species (Lane 1991), and therefore, provision of buffer areas must be adequate to allow for undisturbed nesting behaviour for this species.

Tree-nesting waterbirds

Grey Teal (*Anas gibberifrons*), Pacific Black Duck (*Anas superciliosa*), Australian Shelduck (*Tadorna tadornoides*) and Maned Duck (*Chenonetta jubata*) frequently nest up to a hundred metres or more from the open water of a wetland (Lane 1991). Their nests are situated in hollow limbs or tree forks. These sites offer protection from predators, however, after hatching the young must travel overland to the open water. During this journey they are particularly vulnerable to predation, typically by foxes (*Vulpes vulpes*), ravens (*Corvus* spp.) and possibly cats (*Felis catus*). Under these circumstances, a vegetated buffer zone or vegetated corridor would reduce the predation risk.

In the Vasse-Wonnerup wetlands, Grey Teal and Black Duck nest in Tuart trees (*Eucalyptus gomphocephala*) in the Ludlow National Park (Lane 1991). In this area, predation is heavy when the young travel overland to the Wonnerup.

To protect groundnesting water birds from mammalian predators electric fences have been evaluated in the USA. These were found to be a cost-effective means for the protection of duck populations in managed areas (Greenwood *et al.* 1990). These fences are successful against Red Foxes (*Vulpes vulpes*), Striped Skunk (*Mephitis mephitis*) and smaller species including Franklin's Ground Squirrel (*Spermophilus franklinii*) (Sargeant & Arnold 1984). On the Swan Coastal Plain, fencing (not necessarily electric) the outer perimeter of a buffer zone to exclude mammalian predators, particularly cats and foxes, would substantially enhance the value of the zone as waterbird habitat. Once a fence is erected, baiting programs for foxes could be initiated within the buffer zone. However, these fences would need to be constructed as to not disrupt the seasonal migration nesting activities of species including the Long-necked Tortoise.

Human activities resulting in disturbance

Although human disturbance is recognised as a frequent and increasing threat to waterbird activities associated with wetlands, applicable research is scant (however, see Burger 1981). Human activities can be grouped into four major categories, listed below in order of decreasing disturbance:

1. Rapid overwater movement associated with loud noise (*e.g.* power-boats).
2. Overwater movement with little noise (*e.g.* canoeing).
3. Little overwater movement or noise (*e.g.* swimming).
4. Activities along the shoreline[4] (*e.g.* bush-walking, exercising dogs).

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[4] Note, this can be a substantial disturbance to vegetation unless it is effectively managed.

An adequate disturbance buffer zone would need to incorporate different widths corresponding to the different levels and areal extent of disturbance manifest by these categories. Physical disturbance of wetland vegetation allows for the invasion of weed species and effects the recruitment of native species. Similarly, physical disturbance promotes the spread of "weed" species including *Typha*.

6.10 WATER TEMPERATURE

Riparian vegetation reduces water temperatures by shading the water in a wetland. High water temperatures result in a lowering of the amount of dissolved oxygen that can be maintained in solution (Gnaiger & Forstner 1983) causing conditions deleterious to many fish species (Koehn & O'Connor 1990) and aquatic macroinvertebrates (Hynes 1970). As oxygen is a fundamental component of aerobic decay, reducing oxygen content of a waterbody limits the capacity for assimilation of organic material (Gnaiger & Forstner 1983).

Fringing vegetation keeps lake-water cooler, and therefore reduces the rate of growth and development of invertebrate species. As an example, the pest chironomid species *Polypedilum nubifer*, common to wetlands of the Swan Coastal Plain, is favoured by warmer water temperatures (Davis *et al.* 1988). Temperature also effects migration, spawning and egg development and hatching of many fish species (Koehn & O'Connor 1990), therefore modification of typical temperature regimes may adversely affect these processes.

6.11 HEAVY METALS

Low concentrations of some heavy metals are particularly toxic (*e.g.* cadmium and mercury), affecting the physiology and behaviour of aquatic species. Heavy metals may also be bio-accumulated to many times ambient levels (*e.g.* in freshwater mussels) and may enter other food-chains *via* predators of these mussels.

There are several wetlands on the Swan Coastal Plain that may be affected by heavy metal contamination due to adjacent mineral sands mining and treatment plants. Filtering species within wetlands (*e.g.* the local freshwater mussel *Westralunio carteri*) are a pathway by which heavy metals could enter food-chains. Little is known of the permeability of Swan Coastal Plain soils to heavy metals, however a recent study in upland streams of the Northern Jarrah Forest showed copper binding to organic material within soils at a very small distance (centimetres) from its application to control dieback on haul roads (Alcoa & CSIRO 1991). However, copper was also elevated in streams about 50m from its application on haul roads. This was considered to be due to copper levels being elevated in the surface runoff. Overall however, the transport of heavy metals in surface and groundwater runoff is not well known.

6.12 SCIENTIFIC VALUES

Wetland areas contain many ecotones that are characterised by rapidly changing vegetation structure and species composition over small distances (*e.g.* metres). These areas are typically highly diverse and the scientific value of these areas is usually very high. These areas are therefore important for research into factors regulating biodiversity. Research on important processes over small distances substantially eliminates many of the variables which "confound" the results of research conducted over large distances. Additionally research that increases the understanding of the functioning and processes within wetland ecosystems will greatly enhance successfully management.

6.13 AESTHETIC VALUES

Aesthetic values typically depend upon the extent (*i.e.* the height, width and density) of the fringing vegetation (Lane 1991) required to minimise visual intrusions. Wider buffer zones, particularly those with taller trees, would be necessary to visually block larger developments. Aesthetic values of wetlands can be degraded by the illegal dumping of rubbish. With adequate fencing of a buffer zone, access to the wetland would be reduced and the dumping of rubbish may be minimised. The placement of fences may be sufficient to create an appreciation of an area. Without fences, many people may believe that areas adjacent to wetlands may be used for undesirable purposes including the dumping of rubbish, and in the case of adjacent residential areas, extensive clearing.

7. RECOMMENDED BUFFERS FOR WETLANDS OF THE SWAN COASTAL PLAIN

The adequacy of buffer zones depends on slope, soil type, vegetation, the purposes the buffer is to be used for (Buxton 1991) and the type of adjacent land-use. Adequate widths of buffer zones for fauna protection need to be species-specific; for both aquatic and adjacent terrestrial invertebrates, an adequate buffer may be a few metres, however, for vertebrates associated with wetlands, hundreds of metres may be required. Clearly, the life history of species to be protected within or by buffer zones needs to be known in the setting of an appropriate buffer.

The following criterion-based buffer zone widths are recommended for wetlands on the Swan Coastal Plain (Table 4). Recommended widths for buffer zones are presented on an issue by issue basis and where possible use the results or recommendations from research specifically conducted on the Swan Coastal Plain. Where this was not possible, results from other studies have been extrapolated to the Swan Coastal Plain with modifications allowing for the unique geomorphology and specific threats to Swan Coastal Plain wetlands.

The following recommended buffer widths for wetlands on the Swan Coastal Plain are criterion-based meaning the widths are determined by the major buffer issue in the catchment. Although in this guide, the boundary of the wetland is considered the extent of the wetland-dependent vegetation, for some buffer issues (*e.g.* nuisance insects) the wetland-dependent vegetation will be a part of the effective "buffer zone". Figure 2 and Table 4 show how to determine where measurements of a buffer zone are made from (*i.e.* from the permanent water level, the seasonal inundated zone or the wetland-dependent vegetation).

Buffer zone widths are dependent, *inter alia* on what the wetland needs to be buffered from. To minimise disruption of carbon flow for the maintenance of ecological processes, a 20 to 50m buffer is considered adequate (Table 4). A buffer width of 200m is recommended between intensive practices involving high application of nutrients to sandy soils and 100m for non-sandy soils. Disturbance of waterfowl will be species-specific however, the 50-800m for North American species (Table 3) is within the range expected for Western Australian species. Figure 2 shows a stylised representation of the recommended buffer zones.

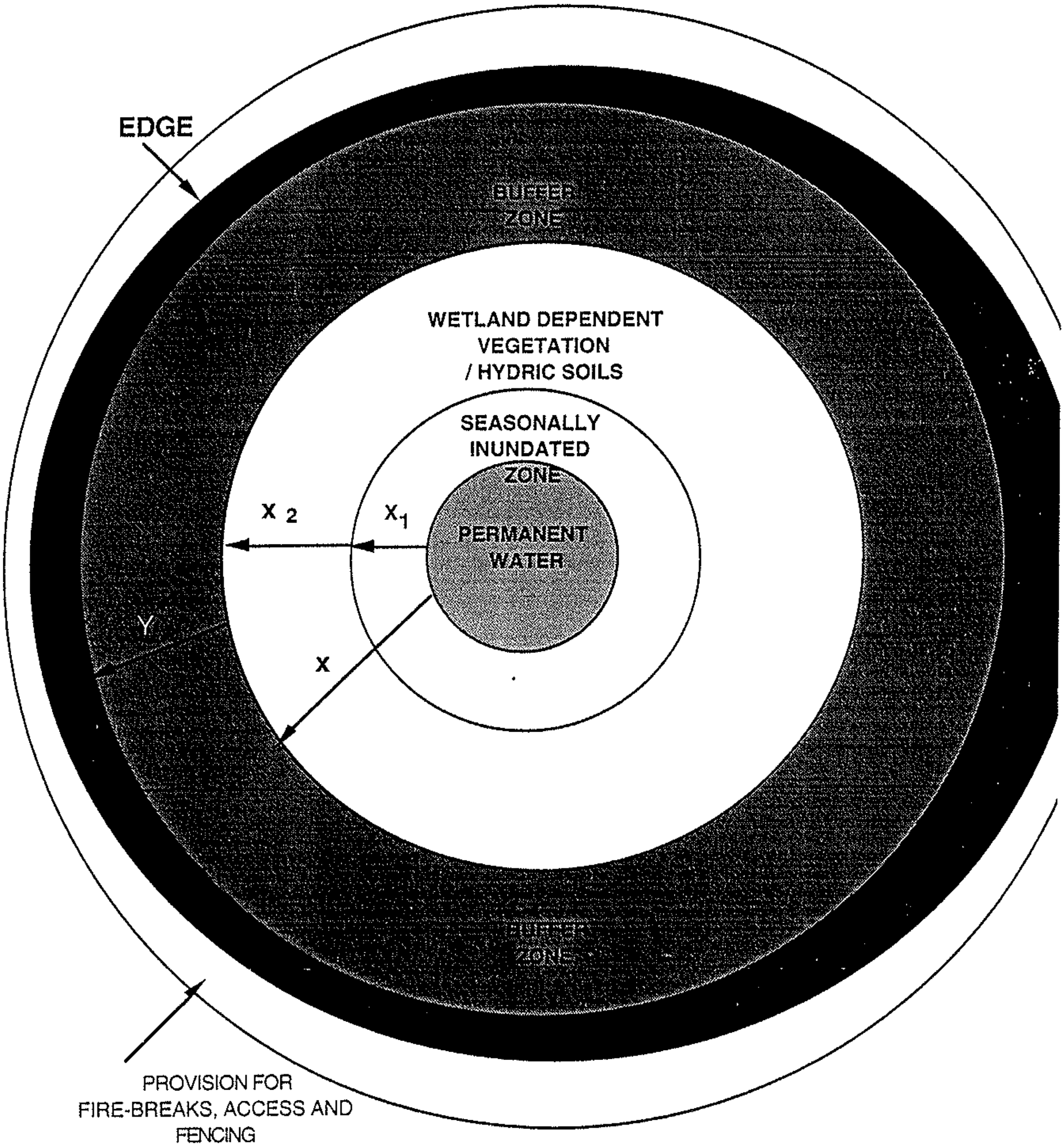

Figure 2. A stylised representation of a wetland illustrating the different zones.

X_1=The extent of the seasonally inundated zone.

X_2=The extent of wetland dependent vegetation.

Y=The buffer zone.

EDGE=The provision for "edge effects" (see Section 7.1).

Provision includes land set aside for firebreaks, fence, management vehicle access (at least a light 4WD, with bays for passing/turning placed at regular intervals) boundary inspection and routine fence maintenance.

Table 4. A summary of recommended widths for adequate buffer zones for different issues on wetlands of the Swan Coastal Plain. Note, these values are an estimate of adequate widths for each major buffer "issue". To more accurately determine appropriate buffer widths, relevant research would need to be conducted for each "issue" on an individual wetland basis.

BUFFER FUNCTIONS	*MEASUREMENTS MADE FROM THE OUTER EXTENT OF:*	*RECOMMENDED BUFFER WIDTH (see Figure 2 for the position of X,Y etc)*
6.1 Carbon flow	Permanent water ·	X + Y=20-50m
6.2 Nutrients[5]	Wetland dependent vegetation	Y=200m on sandy soils Y=100m on non-sandy soils
6.3 Salinity	Wetland dependent vegetation	Y=250m
6.4 Nuisance insects	Permanent water	X + Y=100-800m
6.5 Sediment	Seasonally inundated zone	X_2 + Y=100m
6.6 Rising water levels (Tidal wetlands only)	Depending on slope of adjacent land. Estimate using a sea-level rise from 0.2 to 1.4m[6] (Australian Marine Sciences Association 1990).	
6.7 Groundwater protection	Wetland dependent vegetation	Y=2000m
6.8 Disturbance	Wetland dependent vegetation	Y= 0-400m
6.9 Water temperature	Seasonally inundated zone	X_2 + Y=20m
6.10 Heavy metals	Wetland dependent vegetation	Y=100-200m
6.11 Scientific values	Depends on the specific scientific issue of interest	
6.12 Aesthetic values	Wetland dependent vegetation	Depending on slope of land, orientation of development and vegetation density

An adequate buffer zone for maintenance of ecological processes associated with carbon flow is recommended at 20 to 50m. This is measured from the outer edge of permanent water (Table 4). Recommended buffer zones for protection from nutrient inputs range from 100m in non-sandy soils to 200m on sandy soils. These zones are measured from the wetland dependent vegetation. Excessive nutrient inputs can adversely impact on both the aquatic and wetland dependent vegetation component of a wetland. Excessive nutrients in the water result in enhanced algal growth and associated problems with anoxia, odour, botulism *etc*. Increased nutrient inputs into the wetland dependent vegetation can result in increased weed growth which leads to increased fire and, in turn, increased weed growth.

[5]Note, this is assuming the nutrients are not entering the wetland *via* a drain.

[6]In this case, a 1.4m vertical plus the horizontal component is recommended

Salinisation is a problem both to the aquatic component of a wetland and the wetland dependent vegetation. The recommended buffer width for this parameter is 250m measured from the wetland dependent vegetation.

Nuisance insects, predominantly chironomids, pupate from open water and then migrate outwards from the wetland. Therefore, both the wetland dependent vegetation and the terrestrial vegetation represent a buffer between the insects and adjacent properties. In the case of nuisance insects, a buffer zone of from 100 to 800m is recommended. This wide range of values is in recognition of the differing levels of nuisance these insects will cause in different wetlands. Developments downwind of the wetland will be affected to a greater extent than those elsewhere. The buffer zone for nuisance insects is measured from the permanent water.

The recommended buffer width for minimisation of sedimentation is 100m, measured from the extent of the seasonally inundated zone.

For protection of groundwater, a buffer of 2km is recommended. This buffer is measured from the wetland dependent vegetation. Changes in the quantity and quality of groundwater can effect both the aquatic ecosystem and the wetland dependent vegetation.

The recommended buffer width for minimisation of disturbance is dependent on the species involved. Some waterbird species, for example Eurasian Coots, appear to be little affected by disturbance whilst others, *e.g.* Freckled Ducks, may require an extensive buffer zone. The buffer zone for minimisation of disturbance is measured from the extent of the wetland dependent vegetation.

The input of heavy metals can adversely affect both wetland dependent vegetation and the aquatic habitat. The recommended buffer width for protection from this form of pollution is 100 to 200m from the wetland dependent vegetation.

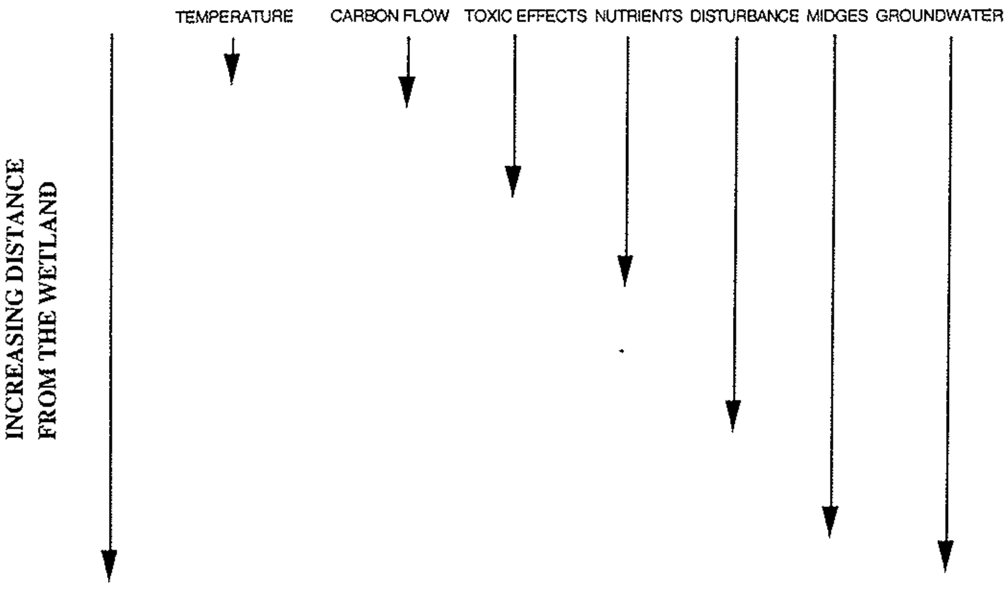

Figure 3. Recommended width for buffers for different threats and processes.

For wetlands of special significance (*e.g.* Ramsar sites, EPA Bulletin 374/686 "Conservation/High Conservation" wetlands, Important Wetlands in Australia (ANCA 1993)), buffer zone widths should be the larger of the recommended buffer-width scale.

Some previous subjective estimations for adequate buffer widths for wetlands on the Swan Coastal Plain are similar to those given in this present document. The Department of Urban Planning and Development recommend a buffer width from 50 to 200m for both lotic and lentic wetlands. Semeniuk & Semeniuk (1992) propose a 100 to 500m buffer for urbanised wetlands of environmental significance. Hill (1992) recommends a 50-200m buffer zone for major rivers and lakes and for systems on marine or aeolian deposits on the Swan Coastal Plain. In the Northern Jarrah Forest, CALM recommends a 500 metre buffer on reservoirs and 20m on a first order[7] stream, 50m for a second order[8] and 100m on a third order stream. In the EPA System 6 Red Book (1993a), buffer widths are recommended to a maximum of 200m. A buffer width of greater than 50m is considered necessary to ensure minimal disturbance of waterbirds in Swan Coastal Plain wetlands, although this buffer need not necessarily totally enclose the wetlands in a buffer (Halse 1991).

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7 A first order stream has no other streams flowing into it.

8 A second order stream is formed by the confluence of two first order streams and so on.

The buffer zone should both protect the wetland and function as a sustainable block of remnant vegetation. To achieve this, a multi-objective management of buffer zones is recommended; that is managing the buffer zone for both wetland protection and as remnant vegetation. Management of these zones should include revegetation of degraded buffer zones with vegetation suitable for maintaining diversity and structure within the prescribed buffer zone.

When defining buffer zones and management strategies, it should be remembered that an ideal buffer would incorporate the extent of the surface and groundwater catchment of the wetland. The recommendations outlined in this document, are less than this ideal and considered the minimum for maintenance of ecological processes, water quality and habitat value of a functional wetland that would, in turn, reduce disturbance to resident fauna and reduce the problems associated with pest species (*e.g.* midges).

Adequate buffers should be of sufficient width, height and structure to maintain wetland functions, maintain water quality and act as a physical barrier to midge swarms and mosquito individuals.

The high conservation value of buffer zones is reinforced by corridor functions (*e.g.* Budd *et al.* 1987, Cohen *et al.* 1987, Mwalyosi 1991) and their remnant nature. The natural environment of the Swan Coastal Plain is highly fragmented, and remnant strips of riparian vegetation can provide linkages between wetland areas. This increases the likelihood of dispersal of flora and fauna for changes in the range of species. Additionally, linkages among remnant patches provide opportunities as refugia when local conditions become inhospitable. For example, elsewhere in Australia, stream-side re-vegetation programs have resulted in the return of the Platypus and White-fronted Chat (Taylor 1986).

7.1 EDGE EFFECTS

Edge effects (*e.g.* weed invasion, increased penetration by light and wind) require an extra area to compensate for progressive degradation of the outer buffer zone. In many cases, an additional 10 to 20m should be added to the outer edge of a buffer zone to reduce the "edge effects" on the vegetation and to allow for possible degradation of the outer edge of the buffer zone.

8. MANAGEMENT OF BUFFER ZONES

8.1 PLANNING PROCESSES

Decisions regarding wetlands and their management should be reached *via* two approaches. "Hard" approaches involve techniques using legislative and regulatory power for wetland protection and "soft" approaches utilise voluntary agreements through shared values and objectives (Burroughs 1993). The "soft" approaches appear to be the more promising in the first instance with "hard" approaches being used when the "soft" have failed. This linked methodology of shared goals and a fall-back position using hard legislative mechanisms is considered appropriate for wetland management on the Swan Coastal Plain.

One of the most important management issues is considered to be the provision of adequate fencing of the buffer zone. Fencing should be completed as soon as the buffer zone is prescribed and should be in place before any local residential or rural development. The type of fence (*e.g.* number of strands *etc*) is similarly an important management issue. Fences and appropriate placed gates should be erected to prevent access by livestock and dogs. It is particularly important to prevent dog access if baiting of foxes is to be undertaken within the wetland and buffer zone. Fencing also restricts access to trail bikes and 4WD vehicles, reducing disturbance to the wetland fauna and flora and lessens the extent of rubbish dumping.

The following stages are recommended to prescribe effective buffer zones around wetland systems on the Swan Coastal Plain:

(1). Define wetland boundary based on wetland dependent vegetation. (Where this is not possible, the maximum seasonal extent of hydric (waterlogged) soils). The Water Authority of Western Australia's (1993) folios are recommended as an initial step for this wetland definition.

(2). Set buffer width by defining major management issues and values under threat. Some modifications of this zone may be appropriate. These could be made following specific research. Additionally, for wetlands where high conservation status has been assigned (*e.g.* Ramsar, EPA "High Conservation/Conservation" category, Bulletin 686, 1993b, "A Directory of Important Wetlands in Australia" [ANCA 1993]) has been assigned, the buffer zone should be increased.

(3). Minimise "edge effects" on the buffer zone vegetation by allowing (dependent on catchment land-uses) an additional 10 to 20m strip of upland vegetation. Also provide an extra strip for firebreaks, vehicle access, fences, *etc.* It is important that this provision take place during the reservation process, rather than afterwards; which is typically the case at present.

(4). Immediately fence the buffer zone and, by definition of the major management objectives and issues, devise appropriate strategies. A linked "soft" to "hard" approach is considered appropriate for buffer zone management.

8.2 REHABILITATION

Determination of appropriate buffer widths may, in many situations, need to be based on the *potential* rather than the existing conditions of a buffer zone. For example, a potential buffer zone may have been extensively cleared of vegetation. Under these circumstances, decisions about buffer zone widths should be based upon their usefulness following successful rehabilitation. Rehabilitation measures should include replanting wetland and terrestrial plant species that are represented in less disturbed wetlands of the area with an appropriate species "mix" (Barling & Moore 1992).

With appropriate rehabilitation, formerly cleared buffer zones can fulfil the function of an undisturbed zone. In addition, assessment of the current value of an existing zone may result in unscrupulous developers deliberately damaging the buffer zone (*e.g.* by overstocking with horses) to gain initial development approval.

For successful rehabilitation, planting should be of appropriate *native* species (see Appendix I) with the associated removal of introduced species including Veldt grass (*Ehrharta calycina*); a species particularly successful on Bassendean Sands. This species chokes native vegetation and represents an increased fire risk. Both Veldt grass and *Typha* are primary invasion, colonising species and once *Typha* has become established, it tends to inhibit the regeneration of other sedges and *Melaleucas* (Arnold 1990).

8.3 COSTS

In the text of this guide, recommended criterion-based buffer widths for a range of buffer issues are shown. However, in many occasions, these recommended widths will not be attained and the provision of buffer zones will be inadequate. This will result in both environmental and economic costs. The following list shows the economic issues related to inadequate buffer zones:

- Increased mosquito/ midge control.
- Flooding control measures.
- Spray systems to aerate potentially anoxic wetlands (*e.g.* Booragoon Lake).
- Nutrient management.
- Control of odour due to eutrophication (*e.g.* requiring harvest of algal material).
- Provision of accessways for tortoises *etc* for seasonal reproductive migration.
- Increased public access resulting in increased disturbance and mitigation measures.
- Litigation for planners after flooding for allowing development of "wetland" areas.
- Mitigation of degraded water quality.
- Removal of invasive, exotic species *e.g. Typha*, Veldt grass.
- Replanting of wetland species and general rehabilitation.
- Botulism control.

These economic costs can be great and not always obvious, due to costs associated with the provision of personnel. For the management of North Lake, tens of thousands of dollars per year are spent on Abate. In Lake Jandebup, the Water Authority of Western Australia provided a pipeline and upkeep to maintain lake water levels. In this case there are both production and provision costs. Table 5 shows environmental problems and economic costs associated with inadequate buffer zones.

Table 5. Some environmental and economic costs associated with inadequate buffer zones. It should be noted that major non-economic costs are the continuing loss of biodiversity.

LIKELY EFFECTS OF AN INADEQUATE BUFFER ZONE	*ENVIRONMENTAL PROBLEMS*	*ECONOMIC COSTS*
INCREASED NUTRIENT INPUTS	EUTROPHICATION	ALGAL HARVESTING
	MIDGE PROBLEMS	SPRAYING
	GROWTH OF WEEDS (*e.g.* promotion of *Typha*)	REMOVAL/ INCREASED FIRE CONTROL
	BOTULISM	CONTROL COSTS
	POTENTIAL LOSS OF SENSITIVE ORGANISMS (*e.g.* Stromatolites in Lake Clifton)	
INCREASED DISTURBANCE	LOSS OF WETLAND VEGETATION, WEED INVASION, REDUCTION IN BIRD NUMBERS	REHABILITATION, PROVISION OF LAND ELSEWHERE
INCREASED WATER TEMPERATURE	INCREASED MIDGE PROBLEMS	SPRAYING
	REDUCTION IN THE ABILITY OF A WETLAND TO ASSIMILATE ORGANIC MATERIAL	COSTS ASSOCIATED WITH AERATION
SALINISATION	LOSS OF SENSITIVE SPECIES	CATCHMENT REPLANTING
	DEGRADATION OF WATER QUALITY	

8.4 INTEGRATED CATCHMENT MANAGEMENT

Integrated Catchment Management (ICM) is an approach to the management of human influences within catchments and recognises the interrelationship between ecological processes, physico-chemistry and land-use practises in a catchment framework (Department of Water Resources 1992). As the buffer zone is a part of the catchment of a wetland, ICM is a valid approach for wetland management. Figure 4 shows the catchment of a wetland divided into 5 zones with a sixth outside the catchment boundary. Different management strategies associated with the different zones are listed below.

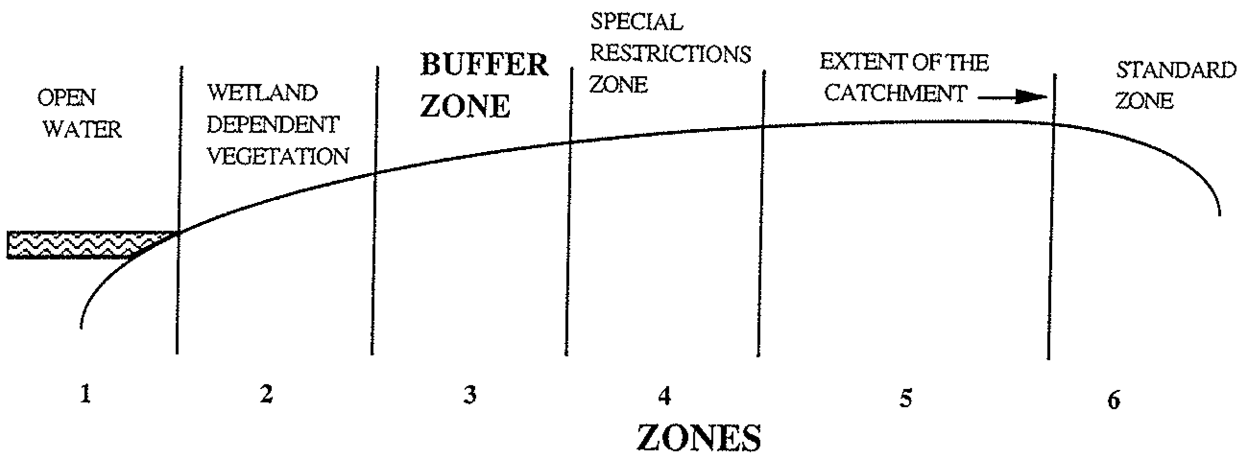

Figure 4. The six-zone model of a wetland catchment.

A six-zone model is convenient to consider when determining appropriate catchment management strategies (Figure 4, modified after Nieswand *et al.* 1989).

ZONE 1 The open water zone.

ZONE 2 The extent of wetland dependent vegetation.

ZONE 3 The buffer zone.

ZONE 4 Special restrictions zone. This is an area of regulated land-uses. This is in recognition of the function of the buffer zone which is not to "accept" and assimilate pollutants from inappropriate upslope land practises. This zone would be subject to standards regarding permitted land use activities. These would be set after determining potential contributions to the pollutant load to the wetland.

ZONE 5 This is an area upslope of the special restrictions zone and is categorised as a zone in recognition of the less critical nature of the area to impact on the wetland. This area incorporates the most upslope regions of the catchment and the watershed boundary.

ZONE 6 The "standard" zone is outside the catchment of the wetland. Land use practises need to recognise the importance of airborne pollutants being deposited into the wetland.

These six zones can be used to define the catchment of a wetland. This present guide outlines the determination of the width of the wetland dependent vegetation and the buffer zone. To determine the width of the special restrictions zone is beyond the scope of this document, although the principals of "water sensitive design" (*e.g.* Department of Planning and Urban Development, Water Authority of Western Australia and the Environmental Protection Authority 1993) are useful to determine suitable management practices.

9. RECOMMENDATIONS FOR FUTURE RESEARCH

(1). Determine the specific effectiveness of different width buffer zones to reduce nutrient inputs into wetlands.

(2). Assess the conservation value of remnant vegetation associated with wetlands.

(3). Examine the critical linkage between the terrestrial and aquatic component of wetlands. This will show the degree to which the aquatic component is reliant upon the input of energy from the terrestrial ecosystem and *visa versa.*

(4). Conduct an audit on the total economic costs associated with management of inadequate buffer zones (see methodology of Thibodeau & Ostro 1981).

(5). Define the floral diversity of palusplains. Palusplains are highly biodiverse but only contain surfacewater seasonally. Current assessment measures (*e.g.* EPA Bulletin 686, 1993b) do not adequately assess the significance of these regions.

(6). Assess the validity of utilising the model of Integrated Catchment Management (ICM) to buffer management. In addition, "water sensitive design" (*e.g.* Department of Planning and Urban Development, Water Authority of Western Australia and the Environmental Protection Authority 1993) should be considered for placing residential developments in a catchment context.

(7). Conduct long-term multi-disciplinary research to gain an understanding how the various components of the landscape integrate to influence important processes within wetlands.

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Appendix I. Wetland dependent vegetation useful to determine wetland boundaries in a number of systems on the Swan Coastal Plain. See Froend *et al.* (1993) for further details.

INDICATOR SPECIES	SYSTEM	REFERENCE(S)
Melaleuca cuticularis	Lake Sumpland Salt marsh	EPA (1993a) Semeniuk *et al.* (1990) Pen (1983)
Banksia littoralis	Lake Lake Palusplain	EPA (1993a) McComb & McComb (1967) Wetlands Advisory Committee (1977)
M. preissiana	Sumpland	Semeniuk *et al.* (1990)
M. rhaphiophylla	Dampland Salt marsh/River Lake	Semeniuk *et al.* (1990) Pen (1983) McComb & McComb (1967)
M. teretifolia	Dampland	Semeniuk *et al.* (1990)
M. lateritia	Guildford clays freshwater	G. Keighery[9]. pers comm.
M. uncinata	seasonally inundated	Department of Conservation and Environment (1980)
M. hamulosa	Salt marsh	Pen (1983)
Acacia saligna (disturbance species) *Acacia dentifera* (Serpentine River)	Lake River	Semeniuk *et al.* (1990) G. Keighery pers. comm.
H. angustifolium	Sumpland	Semeniuk *et al.* (1990)
Typha orientalis	Lake River	Semeniuk *et al.* (1990) Pen (1983)
Leptocarpus spp.	Lake	Semeniuk *et al.* (1990)
Kunzea ericifolia (not good indicator; widespread).	Sumpland	Semeniuk *et al.* (1990)
Eucalyptus rudis	Sumpland Lake	Semeniuk *et al.* (1990) McComb & McComb (1967)
Halosarcia halocnemoides	Sumpland Salt marsh	Semeniuk *et al.* (1990) Pen (1983)

[9]Department of Conservation and Land Management, Woodvale, W.A.

Appendix I (cont.). Vegetation useful to determine wetland boundaries in a number of systems on the Swan Coastal Plain.

Halosarcia. spp.	Salt marsh	Pen (1983)
Juncus kraussii	Sumpland Salt marsh/River	Semeniuk *et al.* (1990) Pen (1983)
Baumea acuta	Lake	Keighery (1992)
Baumea articulata	Lake	Semeniuk *et al.* (1990)
B. juncea	River	Pen (1983)
Cenetella orbifolia	Seasonally inundated	Department of Conservation and Environment (1980)
Regelia ciliata	Palusplain	WAWA (1992)
Casuarina obesa	River	Pen (1983)
Sarcocornia quinqueflora	Salt marsh	Pen (1983)
Bulboschoenus caldwellii (annual)	Salt marsh	Pen (1983)
Isolepis marginata (annual)	Salt marsh	Pen (1983)
Polygonum minus	Seasonally inundated	Department of Conservation and Environment (1980)
Scirpus inundatus	Seasonally inundated	Department of Conservation and Environment (1980)
Euchilopsis linearis	Seasonally inundated	Department of Conservation and Environment (1980)
Myoporum gracile	Seasonally inundated	Department of Conservation and Environment (1980)
Triglochin mucronata (annual)	Salt marsh	Pen (1983)
Samolus repens	Salt marsh	Pen (1983)
Suaeda australis	Salt marsh	Pen (1983)
Angianthus preissianus (annual)	Salt marsh	Pen (1983)
A. micropodiodes (annual)	Salt marsh	Pen (1983)
Casuarina. obesa	Saline river	Orr (1986)
Juncus krausii	Saline river	Orr (1986)
Melaleuca viminea	Saline river	Orr (1986)
Baumea juncea	Saline river	Orr (1986)
M. cuticularis	Saline river	Orr (1986)
M. preissiana	Freshwater swamp	Orr (1986)
Lepidosperma longitudinale	Freshwater swamp	Orr (1986)
Typha orientalis	Freshwater swamp	Orr (1986)

APPENDIX II

A LIST OF NPNCA-VESTED WETLAND NATURE RESERVES AND (WETLAND) NATIONAL PARKS ON THE SWAN COASTAL PLAIN

This list includes only those Nature Reserves and National Parks which are vested or jointly vested in the National Parks and Nature Conservation Authority (NPNCA) and include, adjoin or are part of one or more wetlands.

The term **wetland** here includes permanently and seasonally inundated sites (and possibly some waterlogged sites), rivers and estuaries.

Swan Coastal Plain here is from Moore River to Cape Naturaliste and inland to the foot of Darling Range.

The sites are listed north to south.

Wetland	Region	Code		Vesting	Area (km^2)
Res. No. 26125	Dandaragan	26125	Cons of Flora	NPNCA	63.65
Hill River	Dandaragan	33287	Cons of F&F	NPNCA	293.27
Eneminga NR	Dandaragan	27394	Cons of F&F	NPNCA	740.71
Namming NR (Crackers Swamp)	Dandaragan	28558	Cons of F&F	NPNCA	5431.64
Moore River (small section)	Vic. Plains	3345	Cons of F&F	NPNCA	258.97
Moore River NP	Gingin	28462	National Park	NPNCA	17542.60

APPENDIX II (cont).

Lake Wannamal	Gingin	9838	Cons of F&F	NPNCA	159.62
Yurine Swamp	Gingin	9676	Cons of F&F	NPNCA	29.69
Res. No. 31241	Gingin	31241	Cons of F&F	NPNCA	337.04
Bambun-Nambung-Mungala-Wallering	Gingin	26756	Cons of F&F	NPNCA	101
Chandala Swamp	Chittering	37060	Cons of F&F	NPNCA	135.92
Yanchep NP	Wanneroo	9868	National Park	NPNCA	2842.21
Twin Swamps	Gingin	27621	Pres of Fauna	NPNCA	155.28
Ellen Brook	Gingin	27620	Pres of Fauna	NPNCA	67.15
Lake Nowergup	Wanneroo	24581	Cons of F&F	NPNCA	129.13
Lake Joondalup	Wanneroo	31048	Recn & Cons of F&F	NPNCA, Wanneroo	465.39
Malup Island	Wanneroo	21708	Prot of F&F	NPNCA	4.0
Lake Jandabup	Wanneroo	7349	Cons of Fauna	NPNCA	245.69
Herdsman Lake	Stirling	31906	Env Ed, Cons F&F	NPNCA	5.30
Swan River Estuary					
Pelican Point	Subiaco	40891	Marine Park	NPNCA	5.52

APPENDIX II (cont).

Milyu NR (Kwinana Fwy)	South Perth	33803	Cons of F&F	NPNCA	4.4
Alfred Cove/Pt Waylen	Melville	35066	Cons of F&F	NPNCA	8.69
Lake Forrestdale	Armadale	24781	Cons of F&F	NPNCA	246.16
Gibbs Rd Swamp	Armadale	freehold	for a NR	CALM	unknown
Thomsons Lake	Cockburn	15556	Fauna Cons, Research & Drainage	NPNCA	551.03
Banganup Lake	Cockburn	29241	Research & Cons of F&F	NPNCA	253.74
Peel Inlet					
Creery Island area	Murray	8185	Cons of F&F	NPNCA	74.09
Boodalan Island	Murray	33749	Recn & Cons of Fauna	NPNCA, Murray	1.56
Austin Bay and swamp near Pt Birch	Murray	4990	Cons of F&F	NPNCA	1658.79
Lake Mealup	Murray	6627	Cons of F&F	NPNCA	37.07
Res. No. 24739	Murray	24739	Cons of F&F	NPNCA	48.15
Lake McLarty	Murray	39404	Cons of F&F	NPNCA	184.37

APPENDIX II (cont).

Nine Mile Lake	Murray	16907	Cons of F&F	NPNCA	113.06
Harvey Estuary					
Mealup Point	Murray	2738	Cons of F&F	NPNCA	29.50
SE end	Murray & Waroona	23756	Cons of F&F	NPNCA	1019.00
<u>Yalgorup NP</u>	Mh/Waroona/Harvey	11710	National Park	NPNCA	10425
"	" " "	12189	" "	NPNCA	1584
"	" " "	21271	" "	NPNCA	520
"	" " "	22057	" "	NPNCA	360
"	" " "	41160	" "	NPNCA	7.6
Res. No. 12049	Harvey	12049	Water, Cons of F&F	NPNCA	79.42
Res. No. 12632	Harvey	12632	Water, Cons of F&F	NPNCA	38.03
Res. No. 2517	Harvey	2517	Cons of F&F	NPNCA	41.1
Benger Swamp	Harvey	34811	Cons of F&F	NPNCA	112.77
Res. No. 38398	Harvey	38393	Cons of F&F	NPNCA	5.26
Res. No. 16144	Capel	16144	Cons F&F	NPNCA	94.01
Busselton Wetlands					
Vasse Estuary (N side)	Busselton	41568	Cons of F&F	NPNCA	20.92

APPENDIX II (cont).

Vasse Estuary & Sabina River	Busselton	31188	Cons of F&F	NPNCA	
New River	Busselton	41597	Cons of F&F	NPNCA	6.48
Broadwater	Busselton	27080	Cons of F&F	NPNCA	74.77
Note that the following reserves are not NPNCA vested.					
Karakin Lakes	Gingin	7504	Water & Cons of F&F	Min. Water Supply	285.22
Star Swamp	Stirling	39962	Cos F&F, Passive Recn	Stirling	27.99
Brixton St	unknown	unknown	not yet vested	unknown	unknown
Peel Inlet					
entrance channel	Mandurah	not Res yet	unknown	unknown	unknown
Harvey R. (lower)	Waroona	36126	Drainage & Cons of F&F	Min. Water Resrcs	31.10
Kemerton wetlands	Harvey	freehold	unknown	E.D. of CALM	unknown
Res. No. 7684	Capel	7684	Flora, Fauna	Unvested	4