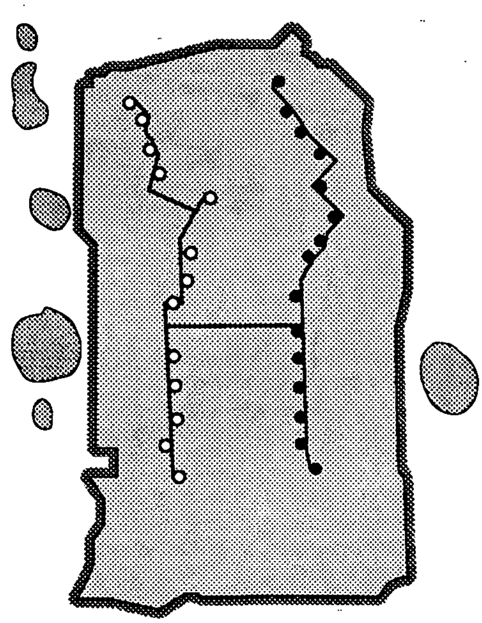
Water Authority of Western Australia

WATER RESOURCES DIRECTORATE
Groundwater Branch

Jandakot Groundwater Scheme Stage 2 Public Environmental Review

Volume 2
Supporting Papers



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Flora and Vegetation

PART A

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September 1988

PREAMBLE

Volume 2

The Water Authority of Western Australia now draws 3 million cubic metres of water each year from the shallow, underground aquifer south of Perth known as the Jandakot Mound. It presently pumps this water from 15 surface aquifer wells and two artesian bores on the eastern side of the mound. By comparison, present licensed wells draw more than twice this amount for agriculture and other private and industrial use.

In Stage 2 of the Jandakot Groundwater Scheme, the Authority is planning on a net private plus Authority use about double the present amounts, with the Authority bores similar to the present but on the western side of the aquifer.

In order to plan environmental assessment and management of Stage 2, the Water Authority commissioned a "desk-top" study to prepare Interim Environmental Criteria. The specialist reports in this volume 2 result from that study.

The study began on 22 August 1988 and finished on 30 September 1988. It was carried out by a core team consisting of Dr Brian J. O'Brien (coordinator), Dr Jenny Davis, Dr Libby Mattiske, Dr Geoff Syme, Dr Duncan Macpherson, Ken Youngson and Jan Henry.

Terms of Reference for the study were fourfold:

- to collate available knowledge
- to summarise the state of knowledge for both local information and relevant environmental criteria in general
- to identify areas where there is insufficient information to allow specific environmental criteria to be determined for the main environmental assessment, and
- to recommend interim environmental criteria.

The purpose generally of the criteria is to determine, via computer modelling of groundwater abstraction, how this abstraction can be managed to optimise water yield while keeping environmental impact within acceptable limits.

Individual papers in this Volume are designed to be stand-alone documents in their own right. Contributors were encouraged to present their individual views with the aim of demonstrating the diversity of the dynamics of these complex environments, and the diversity of priorities favoured by different parts of Nature.

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1. SUMMARY

This report presents a review of environmental criteria for assessing the native flora and vegetation which should be considered in assessing management options for the Jandakot Groundwater Scheme.

Groundwater constitutes a major part of the available water resources of the Perth-Mandurah region. A major consideration in the abstraction of water from the shallow aquifers is the soil moisture requirement of the native flora and vegetation which occur in the wetlands and low lying areas. In previous studies the Water Authority has recognized the need to balance the need for water resources and conservation of native plant communities (Water Authority of Western Australia, 1986).

Many of the native plant species on the Swan Coastal Plain are adapted to a regime of fluctuating groundwater levels (Heddle, 1980; Mattiske & Associates, 1980, 1981, 1982, 1984, 1986, 1988). The short term fluctuations can be illustrated by the changing seasonal levels of many shallow Metropolitan lakes. The questions which arise relate to the degree, extent and duration of the fluctuations that the native plants can tolerate. Predictably, if these fluctuations become excessive then the native plants may not be able to adapt and significant changes will result in the structure and composition of the plant communities. These excessive fluctuations might include a series of below average annual rainfall years (e.g. drought). The ability of different species to adjust to changes in conditions was predicted by Havel (1975) and Aplin (1976). They predicted a shift in the native plant communities to the xeric (drier) end of the continuum if soil moisture levels were lowered on the northern Swan Coastal Plain. This shift has been recorded in the studies on the northern Swan Coastal Plain by Heddle (1980) and Mattiske & Associates (1980, 1981, 1982, 1984, 1986, 1988). Generally, species and communities which tolerate wetter and moister soil conditions are more vulnerable to changes in the water table levels, whether these changes are due to longer term climatic patterns (e.g. periods of below average rainfall years), water abstraction, drainage water diversion, clearing activities, agricultural activities, urbanization or the localized effects of the cone depression near the pumping bores.

Several aspects which arose out of this specific review of environmental issues for the Jandakot Mound were that:

(1) The native vegetation on the Jandakot Mound has been severely affected by European settlement. Therefore the remnant areas that are left are critically important for maintaining some characteristics of the natural environment.

(2) There is a lack of wetlands contained in conservation areas. Therefore the need to maintain areas of native vegetation both within the reserve system and uncleared pockets should be given a higher priority.

(3) A large range of the native species remaining on the Jandakot Mound occur within the lower lying areas which will be affected by changes in the water table regime. The latter is particularly evident in areas within the centre of the Jandakot Mound where clearing activities appear to have avoided seasonally inundated wetlands. Therefore the water resources in the region should be managed in a way that minimizes the degree of impact on the remaining native vegetation.

A few rare and restricted species occur within the Jandakot Mound area. As more systematic botanical studies are undertaken in the area this list is likely to increase. Of those noted to date, several of the species occur in low lying wetland areas. Therefore there is a potential that any changes in the water table levels will influence these species.

On reviewing the available data it was possible to define a series or indicator species in the plant communities to detect past influences and predict future changes. The suggested indicator species may be modified as more studies are carried out in the Jandakot Mound area.

To effectively manage groundwater for the long term maintenance of the wetlands a series of guidelines and criteria have been summarized. The on-going research on the Jandakot Mound will determine the adequacy of some of these criteria. In addition several areas of research have not been addressed. A series of recommendations has been made to cover these aspects.

2. INTRODUCTION

In January 1976, the Water Authority of Western Australia (then Metropolitan Water Supply, Sewerage and Drainage Board) submitted to the Department of Conservation and Environment details of a proposal to abstract groundwater from the Jandakot Mound as an economical means of providing potable water to the community. Two stages to construction and commissioning were proposed. Stage 1 of the scheme included the eastern line of wells (15 surface aquifer and 2 artesian). These wells were commissioned in 1979 and now deliver around 2.7 x 10^6 m^3/year from the shallow aquifer to the public supply system (Water Authority of Western Australia, 1988). Private use of groundwater is licensed by the Water Authority of Western Australia (1988).

In June 1988, the Water Authority of Western Australia applied for an increased abstraction from the Stage 1 line of wells. The Environmental Protection Authority determined that this proposal did not require formal assessment.

The Water Authority of Western Australia is currently reviewing the proposed abstraction of water from a western line of wells (15 surface aquifer and 2 artesian).

This study reviews the botanical and vegetation criteria associated with assessing the impacts of the current and proposed schemes. Several major three year research projects have been initiated to develop more robust environmental criteria for the flora and fauna in the Jandakot Mound Study area. However it is necessary in the meantime to determine a range of interim criteria.

This report therefore aims to review and summarize the presently available information on the effects of abstraction of groundwater on the flora and vegetation of the Jandakot Mound.

3. AIMS

The aims of this review on the flora and vegetation of the Jandakot Mound are to:

- collate available information,
- summarize the state of knowledge for both local and relevant environmental criteria in general,
- identify areas where there is insufficient information to allow specific environmental criteria to be determined for the main environmental assessment, and
- recommend interim environmental criteria.

4. DESCRIPTION OF THE AREA

4.1 Location

The Jandakot Mound occurs to the south of the Swan and Canning Rivers on the Swan Coastal Plain. The study area is defined by the location of the potential water resource and the nearby areas which are likely to be affected by the water abstraction.

4.2 Climate

The Swan Coastal Plain has a typically Mediterranean climate with hot, dry summers and mild, wet winters (Gentilli, 1947, 1951, 1972; Commonwealth Bureau of Meteorology, 1966, 1969). The winter rainfall accounts for the majority of rainfall.

Rainfall data for Perth has been collected for some 112 years (1876-1988). The data reflect extended periods with rainfall above and below the long term average. The last decade has been the driest on record. Seasonal fluctuations in rainfall are reflected in changes in both the soil moisture levels (unsaturated zone) and the water table level (saturated zone). Maximum water table levels are recorded in September-October, and minimum water levels are recorded in April. Super-imposed on these seasonal fluctuations in soil moisture content are the annual fluctuations in rainfall.

The chief deficiency of the climatic records is the lack of evaporation data. Mean daily evaporation is highest during the summer months and lowest during the winter months. Therefore the annual water demand is seasonal, with the greatest use occurring in the hot dry summer months. Consequently, when public water supply, irrigation and environmental demand is greatest there is minimum rainfall and lower groundwater levels. All these factors lead to greater demands on the surface aquifers.

4.3 Landforms and Soils

Essentially the Swan Coastal Plain is formed almost entirely of depositional material from either fluviatile or aeolian activity. The major elements - the Ridge Hill Shelf, the Pinjarra Plain and the three dune systems (Bassendean, Spearwood and Quindalup) have been subdivided into smaller units by Churchward and McArthur (1980). The study area on the Jandakot Mound occurs primarily on the aeolian deposit of differing ages, the Bassendean and Spearwood dune systems, see Table 1. The further divisions of these areas relate to erosional modifications and the incidence and nature of the swamps (Churchward and McArthur, 1980). The area near Lake Forrestdale occurs on the Southern River unit where the sand appears to have been blown over the alluvial soils and so the swamps have a clay base. The areas dominated by peaty swamps were separated into the Herdsman unit.

TABLE 1

Summary of Landform and Soil Units, as defined by Churchward and McArthur, 1980

Bassendean	Sand plains with low dunes and occasional swamps; iron or humus podzols.
Southern River	Sand plains with low dunes and many intervening swamps; iron and humus podzols, peats and clays.
Karrakatta	Undulating landscape with deep yellow sands over limestone.
Herdsman	Peaty swamps associated with Bassendean and Karrakatta units.

4.4 Flora

The Jandakot Mound area is not a "natural" phytogeographical region, but it occurs in the Darling Botanical District of the Southwestern Botanical Province (Diels, 1906). The flora of the Metropolitan Region (Marchant et al, 1987) covers this section of the Swan Coastal Plain.

4.4.1 *Rare and Restricted Flora*

The flora of the study area has not been systematically collected, so the occurrence of rare or restricted flora is not known in details. It is therefore likely that systematic collecting would find additional species in these categories. Two species that are rare are known to occur in the area (Barrett, 1982), these are:

- *Thelymitra* sp. (an undescribed species)
  This species is known from only three collections and occurs from Wanneroo to Jandakot in winter-wet depressions (It is the sp. "A" of Marchant et al, 1987).

- *Lysinema elegans*
  This species is known from three collections (apart from the type) and occurs from Jandakot to Thomsons Lake to Reagans Ford.

There are also species from nearby areas that may occur in the study area. Those of possible concern here are:

- *Cryptandra scoparia*
  This species is known from six specimens in the Metropolitan area and two from Kalbarri (these may represent a different taxa).

- *Schoenus pennisetis*
  This species is moderately widespread but very poorly known with the three specimens at the Western Australian Herbarium coming from Cannington swamp, Dongara and Wongan Hills.

4.5 Vegetation

The first major attempts at defining the vegetation of Western Australia were those of Diels (1906) and Gardner (1942). Their division of the State into botanical provinces and districts formed the basis for later classifications of the vegetation. Speck (1952) classified the vegetation of the Swan Coastal Plain according to its structural and floristic composition. Seddon (1972) summarized Speck's classification for the Swan Coastal Plain. Havel (1968) delineated a series of site-vegetation types for the plant communities on the Bassendean and Spearwood dune systems on the northern Swan Coastal Plain. This study indicated that the determinants of community types were primarily the degree of leaching and the soil moisture levels. Heddle et al (1980) integrated the earlier studies of Speck (1952) and Havel (1968) on the Swan Coastal Plain in defining a series of vegetation complexes for the area.

On a regional basis, Australian plant communities react to drier conditions by changes in their structural and floristic composition. Within a localized area, these changes are further influenced by topography and edaphic factors. In attempting to categorize the plant communities the studies by Heddle et al (1980) achieved a compromise between the broader approaches by Speck (1952) and Beard (1979) and the detailed studies of Havel (1968). The vegetation in the Jandakot Mound area was summarized initially by referring to the vegetation complexes of Heddle et al (1980), see Table 2. The dominant complexes are the Bassendean - Central and South and Herdsman. The other two complexes are restricted to the fringes of the Jandakot Mound area (e.g. Karrakatta - Central and South occurs on the west of Thomsons, Kogolup and Banganup Lakes).

Although there have been some localized botanical studies carried out on the Jandakot Mound they have been limited in their scope to defining the main structural formations and a few dominant species (Cockburn Wetlands Committee, 1976; LeProvost et al, 1987; Arnold, 1988;) In view of the limited time of this study the main community types were extracted from these previous publications, see Table 3. An attempt was then made to summarize these in relation to the major wetland areas, see Table 4. It must be stressed that as this report was prepared without field checking the tables were compiled on the basis of published reports only.

The majority of these vegetation complexes and plant communities, with the exception of the woodlands and forests which occur on the upper slopes of the Karrakatta and Bassendean dune systems (Numbers 1 and 2, see Table 3), are vulnerable to the effects of abstraction of water from the shallow aquifers. The nature of the effects is related to a multitude of factors including the degree, rate and location of water abstraction wells. These will be addressed further in the following sections.

TABLE 2

Summary of Vegetation Complexes, as defined by Heddle et al, 1980

Bassendean - Central and South ranges from woodland of Jarrah-Sheoak-Banksia on the sand dunes, to a low woodland of *Melaleuca* spp, and sedgelands on the low-lying depressions and swamps. *B. attenuata*, *B. grandis* and *B. menziesii* are common on the upper slopes. *B. ilicifolia*, *B. littoralis*, *Melaleuca preissiana* and *M. rhaphiophylla* are common on the low-lying moister soils. Other plant species include *Kunzea ericifolia*, *Hypocalymma angustifolium*, *Adenanthos obovatus* and *Verticordia* spp.

Southern River consists of an open-woodland of Marri-Jarrah- Banksia on the elevated areas and a fringing woodland of *E. rudis-M. rhaphiophylla* along the streams.

Karrakatta - Central and South consists of an open-forest of Tuart-Jarrah-Marri. Common species in the Tuart-Jarrah-Marri open-forest include *B. attenuata*, *B. menziesii*, *B. grandis* and *A. fraseriana*. Shrub species include *Jacksonia sternbergiana*, *J. furcellata*, *Acacia cyclopis*, *A. saligna*, *Hibbertia* spp. *Allocasuarina humilis*, *Calothamnus quadrifidus* and *Grevillea thelemanniana*. On the deeper sands the understorey species show changes and include *Hibbertia hypericoides*, *Conospermum stoechadis*, *Hovea trisperma* and *Bossiaea eriocarpa*.

Herdsman is dominated by sedgelands and a woodland of *E.rudis-Melaleuca* spp., with other species of *Melaleuca* depending on the local drainage and adjacent soils. This vegetation is associated with the series of swamps and small lakes on the Swan Coastal Plain. Other plants include species of *Typha*, *Baumea*, *Juncus*, *Leptocarpus* and *Scirpus*. The vegetation on elevated areas of Herdsman is mainly associated with that of the adjacent landform and soil units.

TABLE 3:

Summary of main Community Types on the Jandakot Mound, extracted from Cockburn Wetlands Committee, 1976; LeProvost et al, 1987; Arnold, 1988)

1. Open forest or woodlands of Tuart (*Eucalyptus gomphocephala*) on the Karrakatta sand dune system on the western fringes of the Jandakot Mound area.
2. Low-open forest to woodlands of *Banksia attenuata-B. menziesii* and the occasional Prickly-bark or Coastal Blackbutt (*Eucalyptus todtiana*) on the Bassendean dune system. *Banksia ilicifolia* and Jarrah (*Eucalyptus marginata*) occur on the moister lower slopes.
3. Fringing woodlands of *Melaleuca rhaphiophylla*, *Melaleuca preissiana*, *Eucalyptus rudis* and *Banksia littoralis*.
4. Low-open woodlands of *Melaleuca preissiana* with a very dense shrub-layer of seasonally inundated heath species dominated by Myrtaceae species (e.g. *Kunzea ericifolia*, *Pericalymma ellipticum*, *Astartea fascicularis*), i.e. dampland or sumpland.
5. Fringing and intrusive wet sedgelands and reedbeds of Cyperaceae and Restionaceae species with pockets of Myrtaceae and Mimosaceae shrublands (e.g. *Melaleuca teretifolia*).
6. Bare shorelines and mudflats with very shallow margins (see Fauna Section, Ninox Wildlife Consulting, Part B).
7. Woodlands of *Melaleuca rhaphiophylla* in permanently inundated swamps (e.g. the Spectacles).
8. Open, shallow expanses of water (see Fauna Section, Part B).
9. Open, deep expanses of water (see Fauna Section, Part B).
10. Pastures, water meadows, grassy areas or farmland with relict stands of Paperbarks (*Melaleuca* spp.) and Eucalypts (*Eucalyptus* spp.).

TABLE 4

Summary of Community Types
(as delineated in Table 3)
for the main Wetlands and Lakes on the Jandakot Mound

(This table was prepared without field checking, so the data requires future verification. Based on Cockburn Wetlands, Committee, 1976; LeProvost et al, 1987; Arnold, 1988).

	Community Type Numbers (see Table 3)									
Wetland/Lake name	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
North	-	-	+	+	+	+	?	+	+	+
Bibra	-	-	+	+	+	+	?	+	+	+
South	-	-	+	+	+	?	?	+	?	+
Little Rush	-	-	+	+	+	?	?	+	-	+
Yangebup	+	+	+	-	+	?	?	+	+	+
Kogolup	+	+	+	+	+	?	?	+	+	+
Thomsons	+	+	+	+	+	+	-	+	+	+
Banganup	+	+	+	+	+	?	?	+	?	?
Wattleup	-	-	+	+	+	?	?	+	+	+
Spectacles	-	-	+	+	+	?	+	+	+	+
Forrestdale	-	+	+	+	+	+	?	+	+	+
Hird Road	-	-	+	+	+	?	?	+	?	?
Twin Bartram	-	-	+	+	+	+	-	+	-	+
Bartram Rd	-	-	+	+	+	+	-	+	-	+
Solomon	-	-	+	+	+	?	?	+	-	?
Russell	-	-	+	+	+	-	-	+	-	+
Gaebler	-	+	+	+	?	-	-	+	-	+
Beenyup Rd	-	-	+	+	+	+	-	+	-	?
Branch Rd	-	-	+	+	+	-	-	+	-	+

Note: + = Community type recorded at time of study quoted (does not account for recent clearing necessarily)

- = Community type not recorded

? = Information not available

5. PREDICTION OF IMPACTS OF GROUNDWATER EXTRACTION ON PLANT COMMUNITIES

5.1 The Jandakot Groundwater Scheme

The water supply for the State is the responsibility of the Water Authority of Western Australia. Demand for water has in the past been met by damming rivers in the Darling Ranges and from underground aquifers on the Swan Coastal Plain. The expansion of the Jandakot Mound Scheme to Stage 2 has been proposed to meet the ever increasing needs for the growing population of Perth. The options for the Authorities are:

- to restrict the population of Perth,
- to alter the pattern and degree of usage of water, or
- to develop further water supplies.

The shallow unconfined aquifers underlying primarily the Bassendean landform and soil unit are known as the Gnangara and Jandakot Mounds.

The Water Authority of Western Australia has established that:

- The lower rainfall recordings between 1976 and 1987 has led to a lowering of the water table on the Jandakot Mound area (0 to 0.4m, change in the minimum water level).

- The impact of the current abstraction of Stage 1 has resulted in a lowering of the water table on the Jandakot Mound (0 to 0.4m change in the minimum water level).

- The impact of the future proposed abstraction could lead to falls in the water table of 0.2 to 1.6m in the minimum water level. The impact is predicted to be greatest on the western edges of the Mound.

- A drawdown of 3 to 4m within the "cones of depression" may occur near the abstraction wells (Metropolitan Water Authority, 1985).

5.2 Wetland Classification

Recognizing that the greatest impact of the current and proposed abstraction of water is likely to be on the wetlands it is important to place an emphasis on reviewing these areas.

The definition of wetlands accepted by the Wetlands Advisory Committee (1979) was:

> "Wetlands are areas of seasonally, intermittently or permanently waterlogged soils or inundated land whether natural or otherwise, fresh or saline, e.g. waterlogged soils, ponds, billabongs, lakes, swamps, tidal flats, estuaries, rivers and their tributaries".

Therefore in the area on the Jandakot Mound there is a large variety of wetlands. Several groups and authors have attempted to develop general classification schemes for wetlands (Riggert, 1966; Tingay and Tingay, 1976; Wetlands Advisory Committee, 1977; C.A. Semeniuk, 1987). The differences in the proposed classification systems also highlighted the variation in data bases for different wetlands. Therefore in this review it was decided to develop concepts and refer to specific wetlands in the development of assessment procedures. The other aspect that has been avoided by some studies is the significance of maintaining native vegetation on adjacent areas.

5.3 Implications of the Jandakot Groundwater Scheme

There are difficulties met in predicting possible influences of the current and proposed abstraction schemes. The Jandakot Mound consists of a complex mosaic of different land uses and remnant areas of native vegetation. In fact only a few areas of uncleared native vegetation are remaining and the majority of these have been subjected to varying levels of disturbance in the past. Also there are growing pressures to develop urbanization through this area. This will lead to additional demands on the groundwater. For example, the proposed housing development to the east of Thomsons Lake may increase the drainage run off, and hence the idea of developing drainage channels to the east of the East Beeliar wetlands.

Research has been carried out previously on the Swan Coastal Plain by the Department of Conservation and Environment, the Department of Conservation and Land Management (formerly the Forests Department), the Water Authority of Western Australia - formerly the Metropolitan Water Authority; CSIRO; McComb and McComb, 1967; Havel, 1968, 1975; Aplin, 1976; How, 1978; Heddle, 1980; Heddle et al, 1980; Mattiske & Associates, 1980, 1981, 1982, 1984; Dodd and Bell, 1982; Dodd et al, 1984; Dodd, 1986; Mattiske & Associates, 1986, 1988).

The general effect of extraction of water from pumping bores of these mounds is a general lowering of the water table over a wide area. As many of the lakes and wetlands are surface expressions of the shallow aquifer, the effects of extraction is predictably most obvious near the wetlands. Bestow (1971) commented, "The drastic lowering of the water table by abstraction will lessen the availability of groundwater to the present plant populations which in consequence, will be reduced".

The implications of developing water supplies on other forms of land use in the South-west was reviewed by Havel (1975). In the same review Havel also referred to the likely shift in the distribution of plant species in response to changes in local conditions.

Aplin in 1976 also predicted a shift in the continuum from the moist phase to the xeric (drier) phase or vice-versa. A shift to the drier or xeric phase of the continuum would result in species which tolerate wetter soil condition being replaced by species which tolerate drier soil conditions. For example, *Banksia littoralis*, which is restricted to the wetter lower slopes and depressions would be replaced by *Banksia attenuata* and *Banksia menziesii* which occur on drier dune slopes. The compounding effects of the invasion of alien plant species, pollution and general degradation of the plant communities was also noted.

It has been pointed out by other authors that the present vegetation is one of our best information sources in our attempts to understand the nature of past vegetation (Smith, 1982). An attempt has been made in the following text to assess the plant communities on the Jandakot Mound. The first impression one gains is that the existing vegetation on the Jandakot Mound has been modified significantly since European settlement. The latter is obvious from the balance of native and introduced or alien species in large sections of the Jandakot Mound and from the lack of upland native vegetation. Further the ring of very large Paperbarks (*Melaleuca preissiana*) and Flooded Gum (*Eucalyptus rudis*) upslope and some distance from the current shoreline of Thomsons Lake (at approximately the 13.5m contour) suggests a higher water-table sometime in the past (an estimate of over 50 and possibly 100 years ago). Therefore although the concept of change is universal, the degree and type of change varies in different sections of the study area.

Miles (1979) in reviewing vegetation dynamics made a useful distinction between fluctuations, where changes occur in detailed composition and structure but the vegetation nevertheless retains its overall character, and successions in which directional change results in vegetation of a different type. In the Jandakot Mound area, European settlement has produced and is continuing to produce changes in the native vegetation. Both the types and rates vary within the study area. In many areas the plant communities have been so greatly affected by clearing and a range of land uses that they no longer have similarities in structure or composition with native areas. The latter is particularly evident on the upper dune slopes where the former (pre-European settlement) *Banksia* woodlands have been cleared and replaced by paddocks of alien grasses and daisies of the families Poaceae and Asteraceae. In determining the effects of the current and proposed water abstraction the multitude of influences in the region has to be recognized. The very nature of biological systems makes the differentiation of effects and causes difficult to assess. One of the difficulties met in reviewing the literature was the lack of data on the effects of the quality of water on the terrestrial plant species which occur on the saturated and unsaturated soil layers. For example, the expansion of reed and sedges (e.g. *Typha*) has been recorded in some wetlands. The quantity and quality of water required for reed-bed management is not currently understood.

Historically, the extraction of water by the Water Authority commenced in 1976 (private pumping occurred prior to 1976) from the Gnangara Mound. This Mound is located primarily on the Bassendean landform and soils. A series of botanical studies was instigated on the northern Swan Coastal Plain in 1976. These studies were established at the time to investigate the impacts of extracting water from shallow underground aquifers. Although similar detailed studies have not been carried out for the Jandakot Mound, it is possible to extrapolate from the northern studies of Havel (1968), Heddle (1980) and Mattiske & Associates (1980, 1981, 1982, 1984, 1986 and 1988) as there are similarities in geology, landforms, soils, climate and soil moisture conditions.

The majority of the data collected by Heddle (1980), Dodd (1986) and Mattiske & Associates (1980 to 1988) reflects the impact of the series of below average rainfall year on the quantity of soil moisture, the water table levels and the native vegetation. Therefore the predicted lowering of soil moisture conditions by drought may indicate possible effects of water abstraction on the Jandakot Mound. Results from these studies indicated that:

(1) The majority of native species on the drier sand dune systems on the Swan Coastal Plain are able to tolerate fluctuations in soil moisture levels.

(2) The species which are known to prefer wet and moist sites are more vulnerable to changes in soil moisture conditions (of both the saturated and unsaturated zone). In areas where the water table levels fell by more than two metres some of the trees and shrubs which prefer wet and moist sites were killed or lost vigour (e.g. *Banksia littoralis*, *B. ilicifolia*, *Eucalyptus marginata*, *Regelia ciliata*, *Hypocalymma angustifolium*, *Pericalymma ellipticum* and *Euchilopsis linearis*, Mattiske & Associates, 1988). The response was gradual in areas where this change was slow, however in areas near the pumping bore cone depressions the changes in overstorey tree species were rapid and relatively widespread (although the loss of mature trees was replaced within several years with younger seedlings and saplings). Therefore if the communities are to be affected, the gradual adjustment of the water table levels appears to be the preferred option. The determination of minimum and maximum fluctuation levels is difficult as the native species can adjust to some changes in water table and soil moisture levels. In this study a conservative approach should be adopted. Consequently it is suggested that fluctuations in water levels should not exceed those recorded in the last decade until further data becomes available.

(3) The older trees are less able to adjust to changes in the soil moisture levels (e.g. results of Mattiske & Associates (1988) for *Banksia littoralis*, *Banksia ilicifolia*, *Eucalyptus marginata* and *Eucalyptus calophylla* on the Gnangara Mound). This appears to be related to the older tree species being unable to adjust their root systems to the modified soil moisture levels.

(4) The older tree species which occur on the moister soil slopes are replaced by younger trees of the same species and younger trees of species which are more drought tolerant. Consequently there has been a shift in the age composition of the overstorey and species composition on the northern Swan Coastal Plain. This shift also included an increase in the distribution of species which tolerated drier conditions down the slope (e.g. *Banksia attenuata*, *Banksia menziesii* and *Scholtzia involucrata*). These responses were particularly obvious in the areas near the cone depressions of pumping bores (Dodd, pers comm. and Mattiske & Associates, 1988).

(5) The species vary in their ability to respond to changes in local conditions. This variation in part relates to their lifeforms, morphology and physiological responses (Dodd et al, 1984; Mattiske & Associates, 1982, 1984; Dodd and Bell, 1982; Dodd, 1986). Consequently the deeper-rooted species are more likely to be affected by water-table drawdown than the shallow-rooted species.

(6) A series of indicator species of change can be selected for varying influences such as fire and soil moisture changes. For example the series of groupings defined by Havel (1968) for the northern Swan Coastal Plain, combined with the root morphological studies carried out by Heddle and Dodd can delineate a range of indicator species. The most obvious ones to date are the two Banksia species which tolerate wet and moist soil conditions respectively, namely - *Banksia littoralis* (which has died and not re-established in some wetlands on the northern Swan Coastal Plain) and *Banksia ilicifolia* (which has shifted its age distribution and distribution patterns in relation to changing soil moisture conditions on the northern Swan Coastal Plain). Similar species can be selected from the range of shrub and understorey species which occur on the Swan Coastal Plain (Mattiske & Associates, 1988).

Sections of the monitoring programme on the northern Swan Coastal plain have been established for some 22 years (1966 - 1988). The latter monitoring programme has been expanded by the Water Authority in recent years to encompass the expansion of the water supply schemes in the northern part of the Gnangara Mound and the Jandakot Mound. As more results become available from this botanical research the implications for management of the Mounds will be clearer.

6. AVAILABLE INFORMATION

As indicated in previous sections the level of information varies between wetlands and areas of low lying vegetation that are likely to be affected by the current or proposed water supply schemes on the Jandakot Mound. The most comprehensive studies that have been undertaken and reported on are those carried out by Cockburn Wetlands Committee (1976), Arnold (1988) and LeProvost et al (1987). Many others include brief reference to the plant species and vegetation. The current monitoring programme being undertaken by Mattiske & Associates on a series of wetlands and communities in the area should provide a more detailed coverage of the plant communities and their floristics. Only then will it be possible to re-assess the conservation status of some of the flora and plant community types. Nevertheless from the reconnaissance trips undertaken in the area and from a review of the aerial photographs it is possible to support the following comments:

(1) That the vast majority of the vegetation on the Jandakot Mound has been cleared, grazed or influenced by urban, industrial, rural, drainage and agricultural activities (see aerial photographic coverage of the study area and comments and tabulations by Arnold for the East Beeliar Wetlands, 1988).

(2) That the wetlands are variable within the Jandakot Mound and on the Swan Coastal Plain. For example, the Spectacles provides a distinct woodland of *Melaleuca rhaphiophylla* (although regenerating in parts), which elsewhere has been largely cleared in the Jandakot Mound area; while the open water, sedgelands, reedlands, heaths, mixed woodlands and shrublands around Thomsons Lake provide a diversity of habitats (as defined by structural and floristic components) not replicated in other nearby wetlands.

(3) That the wetlands owe their origin, type and maintenance to a variety of factors. For example the underlying soil conditions on the Southern River wetland areas are distinct from those on the Bassendean dune system (Churchward and McArthur, 1980, and Table 1).

(4) That a group of wetlands unless they contain a representative of each wetland type of the region cannot be considered to be representative of that region as a whole.

(5) That the condition of a wetland, its potential for disturbance and its land tenure and vesting will affect the ability of the authorities to manage the resource in the longer term.

Prior to assessing the conservation potential of the wetlands it is necessary to delineate the types of wetlands that occur in the local and regional area and then review the significance of individual areas. Obviously within the terms of reference it is not possible to define the variety of wetlands and plant communities on all the wetland areas on the Jandakot Mound. Consequently this report will concentrate on concepts and summarize specific data where it is possible to find examples within the literature.

7. RELEVANT ENVIRONMENTAL CRITERIA

The following environmental criteria have been extracted from the literature and discussions with colleagues. Obviously there is some overlap with previous documents and the author recognizes in particular LeProvost et al (1987), Arnold (1988), Ninox Wildlife Consulting, the Wetlands Advisory Committee, the Environmental Protection Authority, Neville Marchant and Jenny Arnold.

Before assessing the environmental criteria of an area the following aspects require definition. There may be scope for re-ordering priorities.

(1) Define the biological and physical resources of the area, at a species and community level.

(2) Review the regional and local conservation status of plants and communities.

(3) Review the security of land tenure and vesting.

(4) Define the degree of disturbance (on an area basis, ratio of native to introduced species).

(5) Define the potential for disturbance (area/boundary ratios, size of the areas, vulnerability of different systems to pollution and physical disturbance).

(6) Define the likely human use of the area (aesthetics, passive recreation, active recreation, scientific and/or educational study).

(7) Define historical and heritage values.

(8) Review other likely options for the future for each area (e.g. changing usage by birds, altered plant community structures, location of future residential area, future location of transport route).

Note it must be stressed that it is important not to pre-empt changing values and attitudes in the community, while recognizing legal commitments (e.g. Wildlife Conservation Act, CALM Act).

In undertaking assessments of individual areas, it is also important to recognize their combined value. For example it is unlikely that any one wetland would cover the range of plant species or communities within a local or regional overview.

The assessment of the native vegetation areas on the Jandakot Mound has been limited by the lack of data in some areas. However it is still possible to place value judgements on wetlands (see LeProvost et al, 1987). The following examples from the Jandakot Mound were used to illustrate specific points.

If there is Rare or Restricted Species present then the scientific value and the social obligation to conserve genetic diversity is increased

Although rare and restricted species have been noted for the area, insufficient data is currently available to compare or assess the areas of native vegetation.

Is there a range of plant species?

Some of the smaller sumplands and damplands support a large number of species and therefore despite their size and possibly lack of appeal (due to lack of open water bodies) are significant for the conservation of a large number of native species in the region. These areas like the upper slopes are often overlooked in favour of the more aesthetically appealing open water bodies such as North and Bibra Lake (which can also be readily seen from a distance).

The greater the area the greater the chance of maintaining a range or diversity of species and plant communities in the longer term.

This aspect can be applied to the uncleared and less disturbed areas on the Jandakot Mound area. Areas that are ranked high in this category are Thomsons Lake, Banganup Lake, Yangebup Lake, Bibra Lake, Forrestdale Lake, Modong Reserve (south of Thomas Road, and therefore beyond the immediate Jandakot Mound study area), Jandakot Airport and the northern Spectacles.

The higher diversity of plant communities the greater the scope for shifts along the continuum within the local environment

Few areas fall into this category as many areas support only several types of wetlands and fringing vegetation, so the diversity of species is substantially lower. For example, housing occurs in close proximity to the edges of Lake Forrestdale. The latter close proximity of disturbance has resulted in alien species (e.g. Arum lily) invading the undergrowth. In contrast the dunes around Thomsons Lake have restricted the degree of disturbance, while providing a range of plant communities (e.g. *Baumea* sedgelands, *Leptocarpus* sedgelands, mixed Myrtaceae heaths and shrublands, woodlands of Paperbarks (*Melaleuca* spp.) and Flooded Gums (*Eucalyptus rudis*). In view of the extensive range of wet, moist and dry soil conditions, there is a great deal of scope for shifts of plant communities both up and down the slopes. The width of the upper slopes around Thomsons Lake also provides a buffering from other impacts.

The Regional and Local Significance of the Native Plants and Plant Communities

The Spectacles (northern) is considered to be of high local and regional importance. Although large sections of the swamp appear to have been disturbed in the past, the dense overstorey and size make this area significant near Perth.

The Proximity of other Uncleared or Relatively Undisturbed areas of Native Vegetation

Nevertheless it is important to recognize that the greatest value of an individual wetland is that it provides a link for species migration. If too many of these already isolated remnants are destroyed then the options for species are reduced. Therefore a high ranking must be placed on the series of small, but often differing wetland types within the centre of the Jandakot Mound area.

The Vulnerability of the Plant Communities to Disturbance

Initially it is important to review the vesting and tenure of a particular area. Secondly one must assess the aspect of resilience of the physical landscape and biological systems to disturbance and invasion. These may not always be direct or obvious. Some of these aspects are difficult to define within biological systems. However it is possible to fall back on the concepts of size and variety of habitats to minimize the vulnerability. The conservation reserves obviously provide the greatest scope for protection and conservation of plants and plant communities.

The difficulty comes in comparing the relative values. If one follows the concepts of size, diversity, vulnerability, tenure, vesting, continuity and rarity then the areas that become obviously high in conservation values on the Jandakot Mound area are the chain of wetlands on the East Beeliar Wetlands (and in particular the larger reserves within this chain), the series of sumplands and damplands within and near the Jandakot Mound area and the northern Spectacles (as few areas of these densely wooded regularly inundated swamps remain near Perth), Table 5.

TABLE 5

Priority Ranking of Wetlands based on Flora and Vegetation

Name of Lake or Wetland	*Variety + of Community Types*	*Rare or Restricted Species*	*Weeds*	*Conservation Priority ***
Thomsons	9	?	Dieback & Typha	1 Highest
Banganup	6+	?	?	1 Highest
Spectacles	7+	?	?	3 High
Forrestdale	8+	?	Typha & Arum	3 High
North	7+	?	Typha	5 High
Bibra	7+	?	Typha	6 High
South	5+	?	Typha	7 High
Bartram Road	6+	*	?	8 High
Beenyup Road	5+	*	?	9 Moderate
Little Rush	5+	?	Typha	10 Moderate
Yangebup	7+	?	?	11 Moderate
Kogolup	8+	?	?	12 Moderate
Wattleup	6+	?	?	13 Moderate
Hird Road	4+	?	Arum	14 Low
Solomon	4+	?	?	15 Low
Gaebler	5+	?	?	16 Low
Russell	5	?	?	17 Low
Twin Bartram	6	?	Typha	18 Low
Branch Road	5	?	?	19 Low

The community types may be further defined on the basis of different dominant species. The number of communities defined in Table 5 relate to Table 4.

Note:
+ No. of Communities defined relates to published material and definitions vary between observers (See Table 4 for references).

? Rare or Restricted Species may be present.

* Bartram Swamp includes stand of *Melaleuca cuticularis* (unusual for Bassendean sand-dune system) and Beenyup includes thicket of *Melaleuca leptoclada* (unusual for area).

** Based on Size of Reserve, Degree of Disturbance, Proximity of other uncleared areas and/or reserves, status and vesting, community and species variety.

8. INTERIM ENVIRONMENTAL CRITERIA

The relevant interim criteria relate to the following:

(1) A minimization of drawdown effects in areas of higher conservation potential, particularly those in the highest and high categories (Table 5). The drawdown effects will obviously vary between wetlands, but fluctuations of water levels should be maintained within those recorded for the last decade. Recognizing that we have had a series of below average rainfall years, the minimum levels should not fall beyond those recorded in recent years.

(2) A regular review of these areas to assess any changes in condition, using the indicator species defined by Havel (1968) and Mattiske & Associates (1988) which "tolerate excessive wetness" and "optimum moist sites".

(3) A provision for restricting fluctuations in water table levels to the range experienced within the last decade, recognizing that wider variations have occurred in the past (e.g. stranded older *Melaleuca preissiana* and *Eucalyptus rudis* on the edges of Thomsons Lake, well upslope of the current shoreline). As more data becomes available on the effects of wider fluctuations there should be scope for flexibility in defining regimes. For example, if water levels fall too far in the shallow lake beds the spread of *Typha* may require temporary flooding. Therefore the options must remain flexible in view of the current inadequacies of data and information.

(4) A need for a regular review of botanical data as it becomes available. For example results from the studies by Mattiske & Associates on the Jandakot Mound.

9. RECOMMENDATIONS

The following specific recommendations are based on the available information.

There is inadequate data for a systematic review of the rare and restricted flora.

R1: It is recommended that a botanical study should be undertaken to consolidate all information from the State Herbarium Records and search for any rare and restricted species which may occur within the Jandakot Mound area.

The coverage on plant communities is a little better and with the current studies under way on the Jandakot Mound it will be possible to consolidate the earlier data bases established by Cockburn Wetlands Committee (1976), LeProvost et al (1987), and Arnold (1988).

R2: It is recommended that a botanical survey of all areas of uncleared native vegetation and in particular the wetlands be carried out at the earliest opportunity. The earlier studies should be incorporated into these more comprehensive studies.

The vulnerability of different plant species and plant communities to the effects of drought are relatively well documented for the northern Swan Coastal Plain. The latter has led to the conclusion that as many of the remnant areas of native vegetation occur on wetlands and sumplands/damplands, that the vast majority of remnant areas of native vegetation are likely to be affected to varying degrees by any regional lowering of the water table. In areas where the fluctuations are not likely to exceed a metre the changes will be minimal. In areas where the water-table may change by factors of metres the results are likely to be more obvious (e.g. older trees dying in paddocks, older trees dying on the moister and wetter soils, replacement of older trees with younger seedlings, a shift in the continuum along the topographical range). One management option might include the location of bores into markedly disturbed environments (e.g. as achieved in the adjustment of the bore line on the Pinjar Scheme), thereby reducing the degree of change in water levels in less disturbed sections of the Mound. In view of the degrees of disturbance of the eastern section of the Mound, there may be a case for locating the Stage 2 bores further east away from the series of wetlands which are larger and less disturbed in the East Beeliar Wetlands. Obviously the social aspects also need to be reviewed for this option.

R3: It is recommended that the option of shifting the Stage 2 bores further east into areas of greater disturbance (and hence away from the less disturbed East Beeliar Wetlands) be considered.

Another option could be to redirect discharge or drainage water into areas where a water table is lowered by pumping. This has to be handled with care, as little information is known on the effects of using bore water to supplement wetland systems. The preferred option would be to direct the excess water into disturbed wetlands on semi-cleared areas. The latter tentativeness relates to the lack of knowledge on the relationships between quality of water and native species and flood tolerance of some species.

R4: It is recommended that a study be instigated to review the effects of different water qualities on the terrestrial vegetation, particularly the fringing vegetation.

R4: It is recommended that the aspect of supplementing wetlands or creating ornamental wetlands with discharge and drainage water be reviewed, particularly with attention to nutrient levels and pollution levels.

R6: It is recommended that the aspect of longer term changes in water quality and quantity be reviewed by laboratory trials, particularly on sedge and Paperbark species.

10. ACKNOWLEDGEMENTS

The author would like to thank the other members of the study group and officers of the Water Authority of Western Australia for discussions throughout the preparation of this report.

In addition I would like to thank:

Mr M E Trudgen (Botanist - Rare and Restricted Flora)
Mrs J Barrett (Word Processing)

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JANDAKOT GROUNDWATER SCHEME
STAGE 2

ENVIRONMENTAL CRITERIA
STUDY GROUP

VOLUME 2

Avifauna and Terrestrial Vertebrates

PART B

Prepared For: Brain J O'Brien & Associates Pty Ltd

Prepared by: Ninox Wildlife Consulting

September 1988

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SUMMARY

A brief overview of wetland loss on the Swan Coastal Plain is given and places the Jandakot area in the context of its vulnerable position in the Perth metropolitan area. The objectives of the environmental criteria study group are described, and the means by which these aims were achieved for avifauna and terrestrial vertebrates are explored. Baseline environmental information is collated for the Jandakot area and species lists for preferred habitat types included in an appendix.

Two sets of interim criteria are given. One includes all vertebrates and provides a simple index of the faunal conservation status of a wetland and creates opportunities for modelling the potential effect of drawdown or long-term flooding. The other deals specifically with waterbirds and is based on the very extensive Royal Australasian Ornithologists Union (RAOU) database for the study area. Using a summary of this data it was possible to rank a series of wetlands on the basis of their conservation value. Further, the data enabled selection of several wetlands whose current condition could be improved by artificially raising water-levels such that water is maintained for a longer period in summer.

Suggestions are made for constructively disposing of waste water and include the creation of water-meadows and ornamental lakes. These are considered to be valuable in maintaining waterbird populations and overcoming some of the potentially adverse, localised effects of the groundwater extraction scheme.

1.0 INTRODUCTION

Various figures have been given for the proportion of wetlands which have been lost on the Swan Coastal Plain. Estimates range between 30% (Riggert, 1966) and 75% (Department of Conservation and Environment, 1980). The disparity between these figures probably reflects the continuing attrition of wetlands since 1955 and the currently broader definition of the term "wetland". Riggert (1966) operated from the position of game-bird utilisation of well-defined wetlands while recent workers include ephemeral vegetated depressions and narrow, estuarine fringing formations within their classification.

What is agreed upon is that a significant proportion of the Swan Coastal Plain wetlands have disappeared and the vertebrate fauna dependant upon them is showing the effect. Historically, one of the first major environmental consequences of European settlement was the draining of swamps and lakes in the vicinity of Perth (Serventy, 1948; Seddon, 1972; Beckle, 1980). In an assessment of the vertebrate fauna of the Northern Swan Coastal Plain, How (1978) quotes Riggert's figure of 49% as an estimate of the proportion of wetlands lost between Yanchep and Rockingham by 1966.

Any confusion over the amount of wetland environment lost is irrelevant since it is self-evident that:

(a) a large number of wetlands **have** been alienated;

(b) this alienation process is continuing (albeit with a far greater perception of the potential impact and with the implementation of impact reduction strategies);

(c) no wetland in the immediate vicinity of Perth, including those classified as "A" Class Reserves or those satisfying several criteria for nomination as a Wetland of International Importance, is in a pristine or, in many cases, a semi-pristine condition; and,

(d) all wetlands by their nature are dynamic systems subject to change, and, because of historical pressure, those of the Perth area are in a complex state of flux.

Points (c) and (d), particularly, have management implications for the Water Authority of Western Australia (WAWA) and provide the format within which this report has been structured. Storr (1988) encapsulates the dynamic condition of Perth wetlands well, and his assessment indicates the potential for a process of informed management including artificial manipulation of water-levels in selected wetlands as a management tool. In discussing the birds of the Swan Coastal Plain he states that:

> Many wetlands have been drained; others are now polluted. There has been a decline in deep-water ducks, especially the Hardhead. The degradation or removal of waterside herbage by livestock, farmers and local government "beautification" schemes (requiring the reduction of the interface between water and land to a wall) has been accompanied by a decline in the Brown Bittern, Marsh Harrier and Painted Snipe.

In direct reference to the instability of coastal plain wetlands due to accidental or planned intervention, Storr considers that:

> White-backed and Welcome Swallows have benefitted from the greatly increased availability of nest sites as well as the opening of the country. The recent southward spread of the White-winged Fairy-wren is inexplicable; however, when we compare its success with the failure of its Red-winged congener, we have yet another example of how man everywhere tips the balance in favour of open, dry-country birds over forested, wet-country birds.

His final comment provides a basis upon which benign manipulation, wetland rehabilitation and future management can be structured:

> Following heavy clearing of land there has been a general rise in water tables and creation of new wetlands and enlargement of old ones. The new wetlands tending to be open and shallow, have facilitated the recent colonisation of the Swan Coastal Plain by the Great Egret, Little Egret, Sacred Ibis, Royal Spoonbill and Yellow-billed Spoonbill. There has also been an increase in the number of visiting Pacific Herons, Mountain Ducks and Pink-eared Ducks.

Altering a pristine wetland environment can be fraught with unforseen, and, in general, detrimental effects to wildlife. Altering a system such as the Jandakot wetlands where there are a wide range of historical, current and future human influences, can be compared to opening Pandora's Box. However, given that the Jandakot wetlands are in the metropolitan area and that some, if not all, will inevitably be affected to a greater or lesser degree by development of one form or another, it is crucial that Government departments and private individuals contribute freely and without reservation, after this initial assessment, to a process of mutually agreed compromise. There is no place for fixed philosophical or radical stances; the Jandakot wetlands and their wildlife **will** change and potentially degrade even without the planned housing development or the proposed extensions to the Jandakot groundwater scheme.

In this report our basic premises are that:

- in metropolitan locations wildlife and people will inevitably come into contact;
- both have a right to utilise certain wetland resources without denying the right of the other; and,
- informed management and education can reduce conflict over wetlands to the betterment of both wildlife and humans.

1.1 Study Objectives

In relation to the aquatic and terrestrial vertebrates of the Jandakot wetlands, the main objectives of this report, taken from the background brief supplied by the Water Authority, are to:

- collate available information;
- summarise the state of knowledge for both local information and relevant environmental criteria in general;
- identify areas where there is insufficient information to allow specific environmental criteria to be determined for the main environmental assessment; and,
- recommend interim environmental criteria.

2.0 ESTABLISHMENT OF INTERIM ENVIRONMENTAL CRITERIA

2.1 Collation of Information

As with most studies requiring a broad faunal overview of a wetland system located near a major city, there is a large body of data varying from specific literature on the Jandakot area to detailed references within other studies, passing comments in local handbooks and field guides, extensive data in unpublished field notes, personal communications and individual observations. Some references are very accurate, others anecdotal.

Individually acknowledging each of the contributors to this document in text or on tabulations would be time-consuming and ultimately unproductive. We have therefore provided a reference list, bibliography and acknowledgement of unpublished field notes in Appendix 2. Where data are particularly germane to a discussion or point being made, textual references are provided in the normal convention.

2.2 Baseline Environmental Information

The first task in providing a faunal overview of an area is obviously to find out what is actually, or given the gaps in our knowledge for specific wetland types, potentially there. For this report it was necessary to construct detailed vertebrate fauna lists (Appendix 1A-D) for the whole area rather than incomplete lists for individual wetlands. Secondly, it was possible to take each species of vertebrate, and through an exhaustive literature search, allocate "R" for species recorded in the Jandakot area or "?" for unconfirmed species.

This immediately generated the problems of:

(a) overall vertebrate distribution in the Jandakot area;

(b) habitat sub-set utilisation in briefly sampled wetlands;

(c) how to deal with wetland types about which virtually nothing is known; and,

(d) how to develop functional, interim criteria from the above.

The first aspect dealing with habitat utilisation across the board was summarily dealt with in conjunction with the project botanist by converting or amalgamating defined vegetation communities (Flora and Vegetation, this report) into those recognised by wildlife. These were then listed at the top of Appendix 1A-D and include habitats such as mudflats and open water which cannot strictly be defined as vegetation communities.

Points (b) and (c) presented first-order difficulties. Unless very detailed studies are conducted in specific areas for specific projects (e.g. mine sites) it is most unusual to have precise habitat information supplied with individual records. This is most obvious when dealing with waterbird data, although all experienced field-workers have an actual and intuitive knowledge of the habitat preferences for the group in which they specialise. Data on vertebrate habitat sub-sets in the Jandakot area are, at best, scrappy but inferences for individual wetlands can be made from sources such as the draft Beeliar Plan where details on the proportions of relatively undisturbed and relict habitats are given. We have taken the approach that since any tabulation containing incomplete vertebrate habitat data is liable to be misleading, it is far better to draw on the actual and intuitive knowledge of a range of specialists to fill in known habitat preferences of individual vertebrate species. Appendix 1A-D therefore do not contain actual records from the various habitats, but informed judgements on their putative presence. Detailed habitat lists can result only from long-term studies in a limited area.

Point (d), development of interim criteria, is the area upon which the success or failure of this project hinges. Previous environmental criteria assessments (DCE Bulletin #227, 1986; Semeniuk, 1985) treat vertebrate fauna in a very general sense and rely on the assessor visiting each wetland for a period of time. The scope of this short-term "desk- top" project does not allow for extended visits to every wetland but, rather, calls for a broad overview of current knowledge. Lengthy catalogues of species are, understandably, no longer in vogue. Appendix 1A-D appears to be just such a list. However, when it is understood that these tabulations are a functional tool used in constructing the examples given in Section 2.2.1, their inclusion is warranted.

Appendix 1A has been primarily constructed from several years of study by the Royal Australian Ornithologists Union (RAOU) in the Jandakot area and includes waterbird data for 29 wetlands, some surveyed more intensively than others. Twelve other wetlands are listed, for which there are no comparable data. As waterbirds tend to dominate any conservation assessment of the Jandakot area they have been given a separate appendix. Appendix 1B-D has been derived from the sources acknowledged in Appendix 2.

In passing, the RAOU defines waterbirds as "birds that get their feet wet". Appendix 1B, bushland birds, are species other than waterbirds which are not always associated with wetlands, but do make some seasonal use of inundated or damp locations and adjacent upland vegetation. Most of Appendix 1B consists of passerines or "songbirds" although it has a strong component of non-passerine species. The list ranges from the very large Wedge-tailed Eagle (a non-passerine) to the smallest bird in Australia, the Weebill (a passerine). It also has a significant representation of that group referred to by the uninitiated and the tired professional alike as LBJ's or "little brown jobs". The remainder of the Appendix 1 consists of amphibians, reptiles and mammals, only a limited number of which have strong links with wetlands. All of these vertebrates are an integral part of the Jandakot system and contribute not only to the ecological balance of the area but to the quality of human life.

Appendix 1A-D consists of a list of vertebrates representing the current state of knowledge for the fauna of the Jandakot wetlands. To all intents it is a "complete" list. Any future additions are likely to be vagrants, or species whose ephemeral presence will contribute very little to the overall picture. Some species, in fact, are probably undergoing a process of local extinction. Others, such as the Quokka, have almost certainly travelled this path already.

2.3 Interim Environmental Criteria

In Appendix 1A-D, each vertebrate is matched with a wetland habitat sub-set or series of the same in which it is known to occur. The "ideal" wetland would support all habitat sub- sets and all species in Appendix 1A-D.

For the interim environmental criteria two measures of the conservation significance of a particular wetland have been chosen.The first is a technique which can be used by WAWA staff to rapidly and easily establish a working model of a particular wetland whether it be a deep permanent lake or an ephemeral vegetated depression. It allows fauna other than waterbirds to be included in the model and takes account of upland areas which, while an integral part of a wetland, are not strictly in this category since their fauna differs markedly. In biological terms it makes broad assumptions about wetlands in general in that it scales to the highest common denominator and is therefore an indicator of the wetland's potential rather than a definitive statement on its actual conservation status. Its main value lies in its predictive capacity in that it can give some indication of the potential effect of altering water-levels.

The second method uses waterbirds exclusively and after establishing criteria (Table 1) enables a precise statement to be made on a particular wetland, given that it has been assessed in the long-term by the RAOU or other researchers. It uses a combination of species diversity, abundance, breeding, rare or uncommon species and the potential productivity of a wetland to rank each location.

METHOD 1 - a rough measure based on the principle that good habitat sub-set representation = more vertebrate niches = more species = high conservation value. This method deals with all vertebrate groups in Appendix 1A-D and applies a value of "1" for all species, regardless of their rarity. It is a technique which tends to over-estimate the productivity of a wetland since no loadings are applied to unit area of habitat, disturbance levels or wetland size. Bibra Lake for instance, has a list of 49 species to date (RAOU data) while this technique gives it a potential of 87. However, if Bibra Lake dried out such that extensive areas of mudflat formed, a further 13 migratory wading birds could appear. Specific surveys concentrating on secretive species such as crakes, rails and bitterns could raise the total higher. This method is not a definitive statement on a wetland; it is more an index of its potential. This is a simplistic measure which does not require a detailed knowledge of wildlife and their habitats - this has already been given in Appendix 1A-D. It does require that individual wetlands are adequately described or mapped as has been accomplished for the Draft Beeliar Plan (Arnold in prep.) and the assessment of the wetlands between Thomsons Lake and Forrestdale Lake (LeProvost et al, 1987). It also requires the assessor to have the ability to judge from an aerial photograph or on- site inspection that: Unsurveyed Wetland "A" is most similar in size, structure and vegetation to Surveyed Wetland "B", therefore its species list and conservation significance will be similar.

The various steps in the technique are given below, as are examples of three wetlands of very high, intermediate and low conservation status:

1. Choose a wetland;
2. Assess the habitats available from Arnold (in prep.) or Leprovost et al (1987);
3. Match the above with the habitats given in Appendix 1A-D;
4. Count the number of species for all habitats represented in the wetland (taking care not to double count where a species appears in several habitats);

The total number of species for all vertebrate groups combined gives a measure of the diversity of a wetland and therefore an indication of its conservation status. The waterbird total is the most significant feature of the resulting figure.

EXAMPLE 1: Bibra Lake - Very high priority wetland.

From Arnold (in press) Bibra Lake has substantial areas of:

	Habitat Type
Deep open water	9
Open shallow water	8
Typha and sedges	5
Inundated *Melaleuca teretifolia* thickets	5
Mudflats & very shallow water	6
Fringing *Melaleuca rhaphiophylla* woodlands	3
Parkland and grazed areas	10
Upland *Banksia* woodland	2

Using Appendix 1A-D, Bibra supports, or has the potential to support, **87** species of waterbird, 77 bushland birds, 30 mammals, 36 amphibians and reptiles. This gives a total of 230 species. Bibra can therefore be assumed to be of very high priority conservation status.

EXAMPLE 2: Twin Bartram Swamps - moderately high priority wetland.

From LeProvost et al, (1987) Twin Bartram Swamps have small areas of:

	Habitat Type
Shallow open water	8
Inundated *Melaleuca teretifolia* thickets	5
Typha and sedges	5
Fringing *Melaleuca rhaphiophylla/Eucalyptus rudis* forest	3
Kunzea ericifolia/Eutaxia heath	4
Grazing land	10

From Appendix 1A-D this gives **70** waterbirds, 78 Bushland birds, 28 mammals, 32 amphibians and reptiles. The total number of potential species is 208 making it a wetland of intermediate priority.

EXAMPLE 3: Russell Road Swamp - Lowest priority wetland. (No RAOU survey - does not appear on Table 2).

From LeProvost et al, (1987) it can be seen that Russell Road Swamp supports small areas of:

	Habitat Type
Astartea fascicularis heath	4
Fringing *Melaleuca preissiana* woodland and *Leptospermum ellipticum* closed heath	3
Kunzea ericifolia and *Eutaxia* closed heath	4
Reeds	5

From Appendix 1A-D this gives **47** waterbirds, 65 bushland birds, 28 mammals, 35 amphibians and reptiles. This gives a total of 175 species, making it a wetland of low priority.

As stated previously, this is a very rough measure of wetland significance. It generally scales wetlands higher than they actually are but as this is a constant factor, the results are not influenced unduly and can be regarded as an index. However, as a model to predict the potential effects of lowering or raising water-levels, creating water-meadows out of pasture or acting as a guide to the construction of ornamental ponds it has an important function which it fulfils well. Some examples are given below:

Lowering water levels - this could cause die-off in fringing vegetation (Habitat Type 3, Appendix 1) or deplete nesting trees in inundated areas (Habitat Type 7) with the result that fauna, listed under these habitats would either show a reduction in abundance, (for example less deep, open water would affect diving ducks) or discourage certain species altogether, Conversely, more wading bird habitat would be created (Habitat Type 6) with the exposure of more extensive mudflat areas.

Raising water levels - reeds (Habitat Type 5) could be affected thus denying species such as the Clamorous Reed- warbler or Little Grassbird access to breeding and feeding areas but could benefit species under Habitat Type 10 by creating water-meadows.

Ornamental Ponds - thoughtful creation of areas of the habitats given in Appendix 1A-D could encourage the species listed under each. In essence, therefore,permanently removing a habitat type will adversely affect the species listed while the creation of new habitats will benefit others.

METHOD 2 - The second interim criteria method used is based on the very extensive RAOU database for the Jandakot area. Some locations have been visited many more times than others but even with these constraints it can be considered to give the most reliable, finely-tuned assessment of the Jandakot wetlands. It is based entirely on waterbirds. ROAU names for wetlands are bracketed.

Table 1 lists a series of criteria used to establish the conservation significance of the 41 wetlands shown in Figure 1. No information is available for 12 of these (Table 2). In the main these are damplands, sumplands, or degraded swamps, a wetland type about which very little is known. Section 3.2 comments on such wetlands and it is recommended that a more detailed assessment of their status is made. Similarly, wetlands marked with an asterisk in Table 2 have been surveyed on less than four occasions. This illustrates the incomplete and preliminary nature of this assessment. As stated earlier for habitat utilisation records, detailed species lists are a product of long-term sampling. Also, wetlands such as Mather Swamp, (Freeman Road) Swamp, (Nicholson-Mason) Swamp, Twin Bartram Swamp and Beenyup Road Wetland, likewise with few surveys, might be expected to figure more prominently, perhaps at the "expense" of high ranking wetlands, if further survey work was conducted.

During the literature search no reference to a formal structure of criteria-based assessments of waterbird usage of wetlands was found. Table 1 has been developed by R. Jaensch from the exhaustive RAOU database for the Jandakot wetlands and represents an internal assessment of these areas, and these areas alone, although locations such as Forrestdale Lake have conservation implications throughout the south-west of Western Australia. R. Jaensch (pers. comm.) believes that they accurately reflect the comparative waterbird productivity of each wetland with the proviso that some areas are inadequately surveyed. Thompsons Lake and Forrestdale Lake are well surveyed and have been sampled on 191 and 141 occasions respectively. They are recognised under the RAMSAR Convention as "Wetlands of International Importance" since they satisfy several criteria for nomination, such as being known to support at least 20,000 birds on occasions or supporting at least 1% of the known population of a particular species.

TABLE 1

Interim criteria used to rank wetlands in the Jandakot area (based on RAOU waterbird data 1981- 1988)

Ranking Criteria		*POINTS SCORED* (1)	(2)	(3)	(4)	(5)	(6)
(1)	No. of Species	1-10	11-20	21-30	31-40	41+	
(2)	No. Breeding			1-5	6-10	11-15	16+
(3)	No. of Individuals	1-50	51-250	251-1000	1001-5000	5001+	
(4)	Rare Species				Yes		
(5)	Potential for (4)		Yes				
(6)	Breeding by (4)						Yes
(7)	Potential for (6)			Yes			
(8)	Uncommon Species*			1-5	6-10	11+	
(9)	Potential for (8)	Yes					
(10)	Breeding by (8)					1-5	6+
(11)	Potential for (10)		Yes				

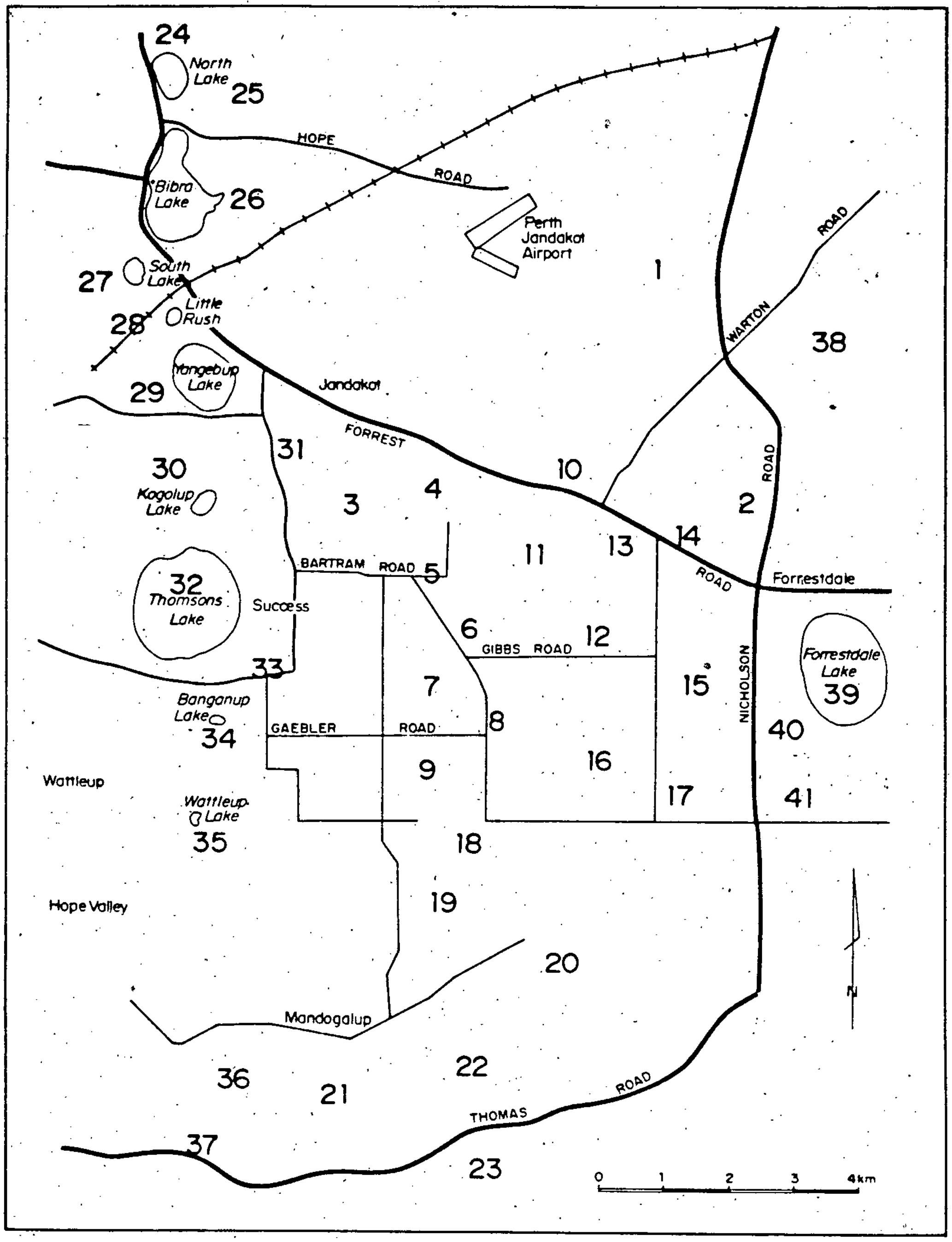
* Uncommon species (in context of South-western Australia). Vagrants excluded.

Bold = known to breed in the region.

Great Crested Grebe
Cattle Egret
Little Egret
Little Bittern
Australasian Bittern
Glossy Ibis
Royal Spoonbill
Yellow-billed Spoonbill
Chestnut Teal
Blue-billed Duck
Baillon's Crake
Australian Crake

Dusky Moorhen
Masked Lapwing
Wood Sandpiper
Marsh Sandpiper
Black-tailed Godwit
Pectoral Sandpiper
Long-toed Stint
Broad-billed Sandpiper
Ruff
Oriental Pratincole
White-winged Tern
Gallinago Snipe

Figure 1 : Location of RAOU field sites on Jandakot Mound



1. (Prison) Swamp
2. (Nicholson - Mason) Swamp
3. Twin Bartram Swamps
4. Solomon Rd. Swamp
5. Mather Swamp
6. Bartram Rd. Swamp
7. Beenyup Rd. Wetland
8. -
9. -
10. (Forrest - Liddelow) Swamp
11. Kraemer Reserve West
12. Boronia Rd. Swamp
13. Kraemer Reserve East
14. (Gibbs - Taylor) Swamp
15. (Gibbs Rd.) Swamp
16. -
17. (Freeman Rd.) Swamp
18. -
19. -
20. (Magenup South) Swamp
21. (Johnson Rd.) Swamp
22. -
23. -
24. North Lake
25a (East Horse Paddock) Swamp
25b (Hope Rd.) Swamp
26. Bibra Lake
27. South Lake
28. Little Rush
29. Yangebup Lake
30a. (Nth. Kogolup) Swamp
30b. Kogolup Lake
31. Hird Rd. Swamp
32. Thomsons Lake
33. Copulup Lake
34. Banganup Lake
35. Wattleup Lake
36. Spectacles North
37. Spectacles South
38. (Warton - Wright) Swamp
39. Forrestdale Lake
40. (James) Swamp
41. (Nicholson - Oxley) Swamp

Note ( ) = RAOU Names

3. WATERBIRD PRIORITY RANKING FOR WETLANDS

TABLE 2

Priority ranking of wetlands based on RAOU waterbird data from 1981-1988. Scores based on Table 1. Codes taken from Figure 1.

I = Wetland of International Importance

* = Less than four surveys of wetland. Ranking is therefore speculative.

Brackets = RAOU names

Rank	*Score*	*Code*	*Name*	*Category*
1	35	39	Forrestdale Lake (I)	**Highest Priority**
2	31	15	(Gibbs Road) Swamp	"
3	30	29	Yangebup Lake	"
3	30	26	Bibra Lake	"
4	29	32	Thomsons Lake (I)	"
5	26	40	(James) Swamp	**High Priority**
5	26*	41	(Nicholson-Oxley) Swamp	"
5	26	30a	(North Kogolup) Swamp	"
6	23*	38	(Warton-Wright) Swamp	"
6	23	24	North Lake	"
7	21*	35	Wattleup Swamp	"
8	20*	36	Spectacles North	"
8	20	27	South Lake	"
9	18	25a	(East Horse Paddock) Swamp	"
10	17*	5	Mather Swamp	"
10	17	33	Gopulup Lake	"
11	15	25b	(Hope Road) Swamp	**Moderate Priority**
11	15	28	Little Rush Swamp	"
11	15*	17	(Freeman Road) Swamp	"
11	15	4	Solomon Road Swamp	"
12	13	10	(Forrest-Liddelow) Swamp	"
13	10*	2	(Nicholson-Mason) Swamp	"
13	10*	3	Twin Bartram Swamps	"
13	10*	6	Bartram Road Swamp	"
13	10*	7	Beenyup Road Wetland	"
13	10*	21	(Johnson Road) Swamp	"

Rank	Score	Code	Name	Category
14	9*	14	(Gibbs-Taylor) Swamp	**Low Priority**
15	8*	30b	Kogolup Lake	"
16	7*	12	Boronia Road Swamp	"
17	5*	1	(Prison) Swamp	"
17	5*	20	(Magenup South) Swamp	"
?	-	8	Unnamed Swamp	**No Data**
?	-	9	Unnamed Swamp	"
?	-	11	Kraemer Reserve West	"
?	-	13	Kraemer Reserve East	"
?	-	16	Unnamed Swamp	"
?	-	18	(Satinover) Swamp	"
?	-	19	(Horseshoe) Swamp	"
?	-	22	(East Treeby) Swamp	"
?	-	23	(Newbold Road) Swamp	"
?	-	31	Hird Road Swamp	"
?	-	34	Banganup Lake	"
?	-	37	Spectacles South	"

3.1 Comments on Specific Zones

Apart from the Beeliar Chain and Forrestdale Lake, the most important of the central zone wetlands appear to be those of the north and east (see Table 2 and Figure 1). In effect, these are the wetlands south of Jandakot Airport and north of Rowley Road, especially those nearer Forrestdale Lake. The substrate, apparently dark heavy clay, and vegetation, taller thickets including *Melaleuca hamulosa*, differs from the sandier, more western wetlands. These north-eastern areas appear to be less modified than the more efficiently drained areas to the south-west.

3.2 The Role of Damplands and Sumplands in Maintaining Waterbird Populations

Semeniuk (1987a) describes a dampland as a "seasonally waterlogged basin" and a sumpland as a "seasonally inundated basin", the main difference being the period over which surface and sub-surface water is maintained. Both are densely vegetated depressions in their pristine or semi- pristine state.

These wetlands are very poorly known and should be targeted before any final decisions are made; they may contribute more to the Jandakot system than is readily apparent. Observations by Roger Jaensch (pers. comm.) suggest that winter-wet damplands and sumplands play the following roles:

Feeding Habitat - they probably operate as feeding areas for uncommon, secretive species such as crakes and rails during winter and, perhaps, spring of normal rainfall years. Four species occur in metropolitan areas such as Herdsman Lake Curry (1981) but are very rarely seen.

Breeding Habitat - in normal years they probably provide nest sites and nursery areas for species that breed in damp areas, dry ground, or very shallow water within dense vegetation. The species involved are Pacific Black Duck, Grey Teal, Australasian Shoveler, possibly other species of duck and the Buff-banded Rail.

Feeding, Breeding and Loafing Areas - in exceptional years when these areas flood and function as a "typical" swamp, they probably offer all the usual habitats for an unusually wide range of waterbirds. Opportunistic species such as most of the ducks, some waterhens, crakes, coots and also perhaps grebes and cormorants are likely to nest in flooded shrubs and sedgeland. Herons and their allies nest in trees if their bases are flooded. It seems that productivity of food items in wetlands that are infrequently flooded is quite high (at least during the first year of inundation, if prolonged) and waterbirds, like most adaptable Australian species, make full use of this resource.

4.0 OPTIONS FOR WATER MANAGEMENT

4.1 Drain East of Beeliar Wetlands

Creation of the Beeliar Wetland Reserve implies a commitment to maintaining or improving their current status. Therefore it would be undesirable to have excessive flooding of these wetlands by nutrient-rich and perhaps polluted runoff. The proposed drain east of Beeliar is an option which should be considered, certainly in terms of the effects, beneficial or otherwise, it may have on fauna. Excessive drying out of wetlands just east of the drain, should they be retained, must be avoided. However there may be some instances where judicious raising of eastern wetland levels could be beneficial, particularly in wetlands that are already greatly modified (see Section 4.2).

This does not apply to western locations such as Yangebup Lake and, probably, several other higher priority wetlands that obtain a proportion of their water supply from westward flowing drains. These proportions should not be altered and if interruption of flow-patterns is caused by the main drain, Thomsons Lake and Yangebup may require "topping up" in winter by ground-water or treated storm-water. Thomsons Lake is of international importance for waterbirds in its present state and although radically altered, Yangebup generally supports the highest numbers of Blue-billed and Pink-eared Ducks in the south-west during the peak of the dry season (Jaensch and Vervest, 1988a and 1988b).

4.2 Water Level Management to Improve Selected Wetlands

Many wetlands on the Swan Coastal Plain, particularly those in the metropolitan area carry high nutrient loads. Apart from occasional outbreaks of botulism and concern by researchers over the long-term effects of heavy metal levels, it appears that waterbirds continue to thrive and are apparently attracted to nutrient-rich areas. With judicious channelling of waste water by a system of carefully located drains (rather than depriving wetlands of a precious resource) it may be possible to improve selected areas where levels are artificially low. A balance between necessity and the potential for waste water to cause unwanted effects needs to be struck.

On the Swan Coastal Plain most wetland water levels are reduced by 0.8 - 1.0m over the dry season and are replenished in early autumn (WAWA data) Wetlands with the greatest diversity and species abundance are those which reach a level where fringing vegetation (potential nesting areas) are flooded in early spring. It is also essential that they are not so deep that they do not dry out or at least expose large expanses of mud in autumn. Many waders rely on the rich feeding grounds formed at the muddy, receding water margin. Therefore, if a wetland basin is steep-sided and has a flattish floor, best results may be obtained if its maximum depth is about 1.0m at the end of winter (Figure 2a). Similarly, if a basin has gently sloping sides, provided they are partly free of vegetation, then deeper inundation (e.g. 1.5-2.0m) in winter/spring may produce equally beneficial results i.e. enhanced breeding, attractive autumn shallows and rich mudflat feeding areas.

With reference to wetland management in the Jandakot area, a basin which usually reaches a depth of no more than 0.5m (Figure 2b) could potentially have another 0.5m added in winter (prior to breeding). This would almost certainly enhance its breeding potential by creating more nesting sites (see previous paragraph) but would not kill vegetation because the wetland would still dry out or become very shallow in autumn. This may not be desirable in "pristine" wetlands (if such a situation exists at all in the Jandakot area) but some of these locations could be greatly improved if they were "topped up" in this way. Final decisions should be made with due reference to the recommendations in Flora and Vegetation (this report).

Conversely, some good or reasonable waterbird refuges may be spoiled by adding too much water. This could have the effect of killing off fringing vegetation and preventing the seasonal exposure of rich feeding areas (see Flora and Vegetation and Aquatic Invertebrates, this report).

It is difficult to set an arbitrary limit on the level at which drawdown will have an adverse affect on fauna since most wetlands differ, not only in their depth, but in other aspects such as breeding locations, refuge areas and feeding zones. Some are pristine, some are semi-pristine and others are totally cleared of vegetation; each fulfils a function for a particular suite of species. A conservative, and probably valid, approach would be to attempt to maintain as far as possible the mean levels measured for the past 10 years. In any event, water-level management should be directed towards maintaining current levels in those wetlands ranked as "highest priority" and "high priority" in Table 2.

Subject to further on-site studies, modelling and discussion with the RAOU and WAWA, the following table of wetlands may be candidates for "topping up". Others may prove to be suitable for this type of management at a later date when more data comes to hand. In general, these wetlands could be improved if water-levels were higher in late summer to pick up the tail-end of breeding and the advent of trans- equatorial migratory wading birds. Extending the period of inundation will raise the abundance of invertebrates upon which many waterbirds feed. Others, if flooded to the point where the bases of trees and shrubs are temporarily covered, will act as breeding refuges with increased protection from terrestrial predators such as foxes and monitors. The primary function of each wetland as a breeding or feeding area (or both) is listed on Table 3.

TABLE 3

List of wetlands which may be suitable for .lm17 enhancement procedures

Code	*Name*	*Comments*
1	(Prison Swamp)	Breeding area
3	Twin Bartram Swamps *	Breeding area
6	Bartram Road Swamp *	Breeding area
7	Beenyup Road Wetland *	Breeding area
10	(Forrest-Liddelow) Swamp *	Feeding area
12	Boronia Road Swamp *	Breeding area
14	(Gibbs-Taylor) Swamp	Feeding area
17	(Freeman Road) Swamp	Breeding area
30	(North Kogolup) Swamp	Breeding/feeding area
34	Banganup Lake ?	Breeding area

(North Kogolup) Swamp (above) has been heavily damaged by horses but currently dries out and has excellent vegetation for breeding. A substantial amount of this activity has already been documented here.

It is worth considering that there may be opportunities for flooding existing flood-tolerant vegetation where this community is normally dry for most of the year (due to past drainage or infrequent natural flooding).

The artificial flooding of open pasture should not be considered wasteful or beyond the realms of possibility. Grazed areas can be converted to water-meadows which are extremely attractive to feeding waterbirds, and in the absence of stock, regeneration/recolonisation by natural vegetation may eventually improve breeding opportunities.An ideal situation is where artificially flooded pasture is situated adjacent to a timbered refuge area i.e. the eastern side of Twin Bartram Swamp. Construction of low water-retaining walls or bunds would minimise alienation of commercial pasture.

In areas where development encroaches upon wetlands and drainage sumps are required, it would be better to amalgamate several of these into an ornamental lake. There are some problems associated with such wetlands, for example, algal growth, excess nutrient loads.and periodic outbreaks of botulism (Swift, 1976). With careful management and specialist advice, however, these areas can contribute to the surrounding natural wetland system by providing additional drought refuges and breeding areas, particularly if they are sensitively landscaped with features such as islands and reedbeds. A variety of water depths and natural plant communities need to be considered. Any management problems will, in the long run, be offset by the advantages of providing not only an additional waterbird resource (given that some wetlands will be alienated by development), but a pleasant environment for people living in the area.

The area of artificially created, thoughtfully designed wetlands for use by waterbirds has much merit provided that problems of water quality can be overcome. Spectacular results could be, and have been, achieved in many places around the world. The Oi Wild Bird Park within the Tokyo metropolitan area, for example, is situated on reclaimed land beneath an expressway and attracts some 125 species of bird including migratory waders. Slimbridge in England is, for the most part, artificially created and functions well. Swift (1976) outlines methods for managing such areas.

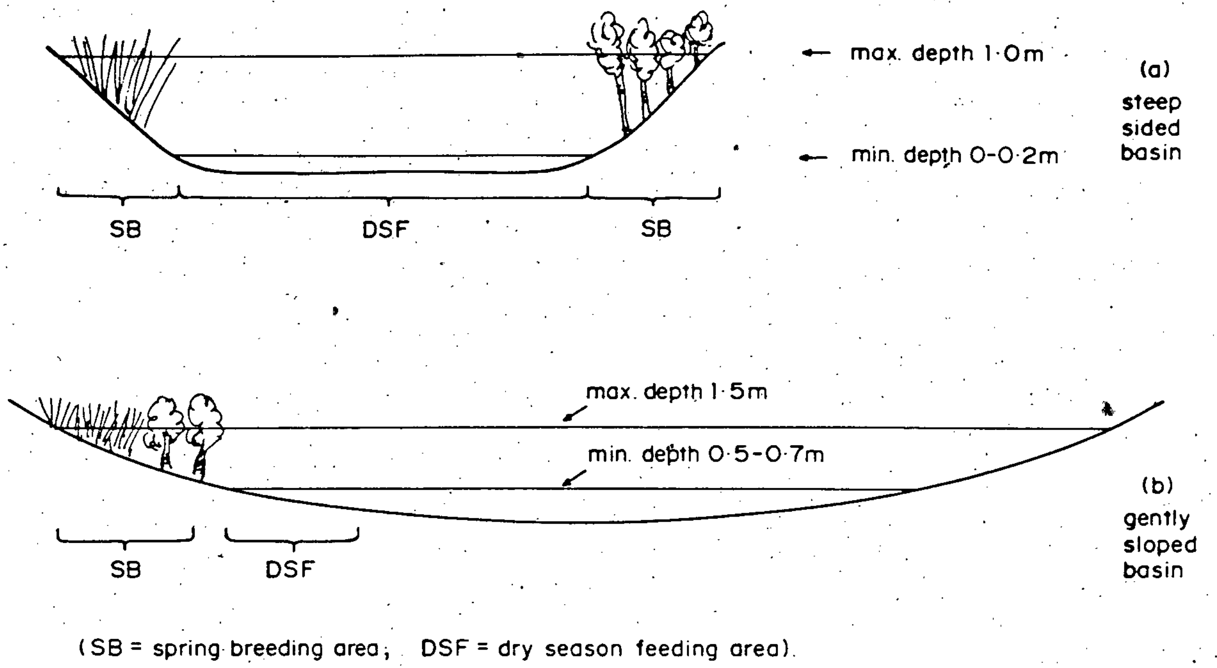


Figure 2 : Examples of wetland basins suitable for water level management

FIGURE 2
Examples of wetland basins suitable for water level management

5.0 ACKNOWLEDGEMENTS

The authors would like to thank the study group coordinator for his direction, and group members for their suggestions. The RAOU provided access to all their data for waterbird surveys in the Jandakot wetlands since 1981. Without their assistance, summaries and guidance, compilation of this report would have been much more difficult. We would also like to thank R. Jaensch and R. Vervest for voluntarily assessing dampland and sumpland areas about which very little is known.

G. Harold and B. Maryon provided access to their detailed amphibian and reptile field notes for the Jandakot area and gave freely of their extensive knowledge of habitat utilisation. The time which they spent visiting the study area at short notice is also gratefully acknowledged.

Special thanks are due to the Water Authority of Western Australia for their continuing support and assistance during this project.

APPENDICES 1A - 1D

Fauna Status Codings and Species Lists

Column 1: R = Recorded in area
? = Unconfirmed species

STATUS IN THE JANDAKOT AREA

Column 2: R = Rare
U = Uncommon
M = Moderately common
C = Common
V = Vagrant
? = Unknown status
A = Predominantly aerial species

The symbol X indicates putative, rather than necessarily observed, presence. Key to fauna habitat codings. Expanded descriptions are given in Flora and Vegetation (this report).

1. Upland woodlands dominated by *Eucalyptus gomphocephala*.

2. Low - open forests of *Banksia attenuata*, *B. menziesii* and occasional *Eucalyptus todtiana*, *E. marginata* and *B. ilicifolia*. The latter two species becoming more dominant in wetter areas.

3. Fringing woodlands of *Melaleuca preissiana*, *M. rhaphiophylla*, *Eucalyptus rudis* and *Banksia littoralis*.

4. Low - open woodland of *Melaleuca preissiana* with a very dense shrub-layer of seasonally inundated heath species dominated by Myrtaceae spp., i.e. dampland or sumpland.

5. Fringing and intrusive wet sedgeland, shrubland (*Melaleuca teretifolia*) and reedbeds.

6. Bare shorelines and mudflats with very shallow margins.

7. Permanently inundated *Melaleuca* woodland (The Spectacles).

8. Open, shallow expanses of water.

9. Open, deep expanses of water.

10. Pasture, water meadows, grassy areas or farmland with relict swamps and associated vegetation.

APPENDIX 1A

List of waterbirds recorded or expected to occur in the Jandakot area
Habitat preferences for each species are listed
(See text, Section 2.2)

1 = Rare and endangered species;
2 = Birds covered by the Japan/Australia Agreement;
3 = Introduced species or aviary escapee.

			HABITAT TYPE									
BIRD SPECIES	*R*	*S*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Podicipedidae												
Great Crested Grebe	R	U					X		X		X	
Hoary-headed Grebe	R	C					X		X		X	
Australasian Grebe	R	C					X		X	X	X	
Pelecanidae												
Australian Pelican	R	U						X			X	
Anhingidae												
Darter	R	U			X			X	X		X	
Phalacrocoracidae												
Great Cormorant	R	U			X				X		X	
Pied Cormorant	R	U			X				X		X	
Little Black Cormorant	R	U			X				X		X	
Little Pied Cormorant	R	M			X				X		X	
Ardeidae												
Pacific Heron	R	U								X		X
White-faced Heron	R	C			X	X	X	X	X	X		X
Cattle Egret 2	R	U										X
Great Egret 2	R	U			X		X	X	X	X		X
Little Egret	R	U			X		X	X	X	X		X
Rufus Night Heron	R	M			X	X	X	X	X	X		X
Little Bittern	R	U				X	X		X			
Australasian Bittern	R	U				X	X		X			
Plataleidae												
Glossy Ibis	R	U						X		X		
Sacred Ibis	R	M			X	X	X	X	X	X		X
Straw-necked Ibis	R	M										X
Royal Spoonbill	R	U					X	X		X		
Yellow-billed Spoonbill	R	U			X	X	X	X		X		

			HABITAT TYPE									
BIRD SPECIES	*R*	*S*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Anatidae												
Wandering Whistling Duck	R	V							X		X	
Black Swan	R	C					X	X	X		X	X
Freckled Duck 1	R	R					X	X	X	X	X	X
Australian Shelduck	R	M	X		X		X	X	X	X		X
Pacific Black Duck	R	C	X		X		X	X	X	X		X
Grey Teal	R	C	X		X		X	X	X	X		X
Chestnut Teal	R	U	X		X		X	X	X	X		X
Australasian Shoveler	R	M					X	X	X	X	X	X
Pink-eared Duck	R	M			X		X	X	X	X		X
Hardhead	R	U					X	X	X		X	X
Maned Duck	R	M	X		X	X	X	X	X	X		X
Blue-billed Duck	R	M					X		X		X	
Musk Duck	R	M					X		X		X	
Exotic Waterfowl & Hybrids 3	R	M			X		X	X	X	X		X
Pandionidae												
Osprey	R	U			X		A	A	A	A	A	
Accipitridae												
White-bellied Sea Eagle	R	U			X		A	A	A	A	A	
Marsh Harrier	R	U			X		A	A	A	A	A	
Rallidae												
Buff-banded Rail	R	?				X	X		X			
Baillon's Crake	R	?				X	X		X			
Australian Crake	R	?				X	X		X			
Spotless Crake	R	?				X	X		X			
Black-tailed Native-hen	R	U				X	X		X			
Dusky Moorhen	R	M				X	X		X			
Purple Swamphen	R	M				X	X		X			
Eurasian Coot	R	C					X	X	X	X		X
Charadriidae												
Masked Lapwing	R	V										X
Banded Lapwing	R	M										X
Grey Plover 2	R	M						X				X
Lesser Golden Plover 2	R	U						X				X
Red-kneed Dotterel	R	U						X				X
Hooded Plover	R	U						X				
Large Sand Plover 2	R	U						X				
Little Ringed Plover	R	V						X				
Red-capped Plover	R	C						X				
Black-fronted Plover	R	M						X				X
Inland Dotterel	R	V						X				

			HABITAT TYPE									
BIRD SPECIES	*R*	*S*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Recurvirostridae												
Black-winged Stilt	R	C						X		X		X
Banded Stilt	R	U					X		X			X
Red-necked Avocet	R	M					X		X			X
Scolopacidae												
Wood Sandpiper 2	R	U						X				
Common Sandpiper 2	R	U						X				
Greenshank 2	R	U						X		X		
Marsh Sandpiper 2	R	U						X				
Gallinago Snipe 2	R	V						X				
Black-tailed Godwit 2	R	U						X		X		
Bar-tailed Godwit 2	R	M						X				
Red Knot 2	R	M						X				
Great Knot 2	R	U						X				
Sharp-tailed Sandpiper 2	R	M						X				
Pectoral Sandpiper 2	R	U						X				X
White-rumped Sandpiper	R	V						X				
Red-necked Stint 2	R	U						X				
Long-toed Stint 2	R	U						X				X
Little Stint	R	V						X				
Curlew Sandpiper 2	R	C						X		X		
Broad-billed Sandpiper 2	R	V						X		X		
Ruff 2	R	U					X	X				
Glareolidae												
Oriental Pratincole	R	V						X				X
Laridae												
Silver Gull	R	C						X	X	X	X	X
Whiskered Tern	R	M					A	A	A	A	A	A
White-winged Tern 2	R	M					A	A	A	A	A	A
Sylviidae												
Clamorous Reed-Warbler	R	M					X					
Little Grassbird	R	M					X					
Ephthianuridae												
White-fronted Chat	R	U						X				X
Grallinidae												
Australian Magpie-lark	R	M			X	X		X				X

APPENDIX 1B

List of bushland birds recorded or expected to occur in the Jandakot area
Habitat preferences for each species are listed

1 = Gazetted species;
2 = Birds covered by the Japan/Australia Agreement;
3 = Introduced species or aviary escapee.

			HABITAT TYPE									
BIRD SPECIES	*R*	*S*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Accipitridae												
Black-shouldered Kite	R	M						A				A
Square-tailed Kite	R	U	A	A	A							
Whistling Kite	R	U			A	A	A		A			A
Brown Goshawk	R	U	A	A	A							
Collared Sparrowhawk	R	U		A	A							
Wedge-tailed Eagle	R	U	A	A								A
Little Eagle	R	U	A		A							A
Spotted Harrier	R	U		A		A						A
Falconidae												
Peregrine Falcon 1	R	R	A	A	A	A	A		A			A
Australian Hobby	R	U	A	A	A	A	A		A			A
Brown Falcon	R	U	A	A								A
Australian Kestrel	R	M						A				A
Phasianidae												
Stubble Quail	?	M					X					X
Turnicidae												
Painted Button-quail	R	U	X									
Columbidae												
Feral Pigeon 3	R	U										X
Spotted Turtle-Dove 3	R	U		X	X							X
Laughing Turtle-Dove 3	R	M		X	X							X
Common Bronzewing	R	M	X	X	X	X						X
Crested Pigeon	R	U										X
Cacatuidae												
Carnaby's Cockatoo	R	C	X	X	X							X
Galah	R	M	X	X	X							X
Little Corella 3	R	U			X							X

			HABITAT TYPE									
BIRD SPECIES	*R*	*S*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Loriidae												
Râinbow Lorikeet 3	R	U	X		X							
Purple-crowned Lorikeet	R	U	X		X							
Polytelitidae												
Regent Parrot	?	U	X									X
Platycercidae												
Red-capped Parrot	R	M	X	X	X							X
Western Rosella	R	U	X		X							X
Port Lincoln Ringneck	R	C	X	X	X	X						X
Hooded Parrot 3	R	U			X							X
Elegant Parrot	R	U			X							X
Cuculidae												
Pallid Cuckoo	R	M	X	X	X							X
Fan-tailed Cuckoo	R	U			X							
Horsfield's Bronze-Cuckoo	R	U	X	X								X
Shining Bronze-Cuckoo	R	M	X	X	X	X						X
Strigidae												
Southern Boobook	R	U	X	X	X							X
Tytonidae												
Barn Owl	?	U	X	X								X
Podargidae												
Tawny Frogmouth	R	U	X	X	X							X
Aegothelidae												
Australian Owlet-nightjar	R	?	X	X	X							X
Apodidae												
Fork-tailed Swift 2	R	M	A	A	A	A	A	A	A	A	A	A
Alcedinidae												
Laughing Kookaburra 3	R	C	X	X	X	X						X
Sacred Kingfisher	R	M	X	X	X	X			X			X
Meropidae												
Rainbow Bee-eater 2	R	C	A	A	A	A	A	A	A	A	A	A
Hirundinidae												
White-backed Swallow	R	M	A	A	A							A
Welcome Swallow	R	M				A	A	A	A	A	A	A
Tree Martin	R	C	A	A	A	A	A	A	A	A	A	A

			HABITAT TYPE									
BIRD SPECIES	*R*	*S*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Motacillidae												
Richard's Pipit	R	M										X
Campephagidae												
Black-faced Cuckoo-shrike	R	M	X	X	X	X	X		X			X
White-winged Triller	R	U		X		X						X
Muscicapidae												
Scarlet Robin	R	U	X	X	X	X						X
Red-capped Robin	R	U	X	X								X
Hooded Robin	R	U		X		X						X
Jacky Winter	R	U		X								X
Golden Whistler	R	U			X	X						
Rufous Whistler	R	M	X	X								X
Grey Shrike-thrush	R	U	X	X	X	X						X
Restless Flycatcher	?	U			X	X						
Grey Fantail	R	M	X	X	X	X						X
Willie Wagtail	R	M			X	X						X
Maluridae												
Splendid Fairy-wren	R	M	X	X	X	X						X
Acanthizidae												
White-browed Scrubwren	R	M			X	X	X					
Weebill	R	C	X	X	X	X						X
Western Gerygone	R	C	X	X	X	X						X
Inland Thornbill	R	C	X	X	X	X	X					X
Western Thornbill	R	M	X	X	X	X						X
Yellow-rumped Thornbill	R	M	X	X								X
Neosittidae												
Varied Sittella	R	U	X	X	X	X						X
Climacteridae												
Rufous Treecreeper	R	?	X									
Meliphagidae												
Red Wattlebird	R	C	X	X	X	X			X			X
Little Wattlebird	R	M	X	X	X	X			X			X
Yellow-throated Miner	R	U	X	X								X
Singing Honeyeater	R	C	X	X	X	X	X		X			X
Yellow-plumed Honeyeater	?	U	X									
White-naped Honeyeater	R	U	X	X	X				X			X
Brown Honeyeater	R	C	X	X	X	X	X		X			X
New Holland Honeyeater	R	C		X	X	X	X		X			X

			HABITAT TYPE									
BIRD SPECIES	*R*	*S*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
White-cheeked Honeyeater	R	U		X	X	X	X		X			X
Tawny-crowned Honeyeater	R	U				X						
Western Spinebill	R	M	X	X	X	X	X		X			X
Dicaeidae												
Mistletoebird	R	U	X	X	X							X
Pardalotidae												
Spotted Pardalote	R	M	X		X							X
Striated Pardalote	R	M	X	X	X							X
Zosteropidae												
Silvereye	R	M	X	X	X	X	X					X
Ploceidae												
Chestnut-breasted Mannikin 3	R	U										X
Artamidae												
Masked Woodswallow	R	U	A	A	A	A	A					A
Black-faced Woodswallow	R	U	A	A	A	A	A					A
Dusky Woodswallow	R	?	A	A	A	A	A					A
Cracticidae												
Grey Butcherbird	R	M	X	X	X	X						X
Australian Magpie	R	C	X	X	X	X		X				X
Corvidae												
Australian Raven	R	C	X	X	X	X		X	X			X

APPENDIX 1C

List of mammal species recorded or expected to occur in the Jandakot area. Habitat preferences for each species are listed

1 = Gazetted species
3 = Feral or introduced species

			HABITAT TYPE									
MAMMAL SPECIES	*R*	*S*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Tachyglossidae												
Short-beaked Echidna	R	U	X	X	X	X						X
Dasyuridae												
Chuditch 1	1928	R	X	X	X	X		X				X
Yellow-footed Antechinus	?	?			X	X	X					
Common Dunnart	?	?	X	X	X	X						X
Myrmecobiidae												
Numbat 1	1982	R	X	X								
Peramelidae												
Southern Brown Bandicoot	R	M	X	X	X	X	X	X				X
Phalangeridae												
Common Brushtail Possum	R	U	X	X	X							
Burramyidae												
Western Pygmy-possum	?	?	X	X	X	X						
Tarsipedidae												
Honey-possum	R	?	X	X		X						
Macropodidae												
Western Brush Wallaby	R	?		X	X	X						
Western Grey Kangaroo	R	?	X	X	X	X	X	X				X
Quokka	1961	?			X	X						
Molossidae												
White-striped Mastiff-bat	R	?	A	A	A	A	A	A	A	A	A	A
Little Mastiff-bat	?	?	A	A	A	A	A	A	A	A	A	A

MAMMAL SPECIES	R	S	1	2	3	4	5	6	7	8	9	10
							HABITAT TYPE					
Vespertilionidae												
Greater Long-eared Bat	R	?	A	A	A	A	A	A	A	A	A	A
Gould's Long-eared Bat	R	?	A	A	A	A	A	A	A	A	A	A
Lesser Long-eared Bat	?	?	A	A	A	A	A	A	A	A	A	A
Gould's Wattled Bat	?	?	A	A	A	A	A	A	A	A	A	A
Chocolate Wattled Bat	?	?	A	A	A	A	A	A	A	A	A	A
Great Pipistrelle	?	?	A	A	A	A	A	A	A	A	A	A
King River Eptesicus	R	?	A	A	A	A	A	A	A	A	A	A
Muridae												
Water-rat	?	?			X	X	X	X	X	X		
Southern Bush Rat	?	?			X	X	X	X	X			
Ashy-grey Mouse	?	?		X								
Black Rat 3	R	C			X	X	X	X	X	X		X
Brown Rat 3	R	?			X	X	X	X	X	X		X
House Mouse 3	R	C	X	X	X	X	X	X				X
Leporidae												
Rabbit 3	R	C	X	X	X	X						X
Canidae												
Fox 3	R	M	X	X	X	X	X	X		X		X
Felidae												
Feral Cat 3	R	C	X	X	X	X	X	X				X

APPENDIX 1D

List of amphibian and reptile species recorded or expected to occur in the Jandakot area. Habitat preferences for each species are listed.

1 = Gazetted species

			HABITAT TYPE									
AMPHIBIAN and REPTILE	*R*	*S*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
LEPTODACTYLIDAE Frogs												
Crinia georgiana	R	U			X	X	X					
Heleioporus eyrei	R	C	X	X	X	X	X					X
Limnodynastes dorsalis	R	C	X	X	X	X	X					X
Myobatrachus gouldii		R	C	X	X							
Pseudophryne guentheri	R	C	X	X	X	X	X					
Ranidella glauerti	R	C			X	X	X					
R. insignifera	R	C			X	X	X					X
HYLIDAE												
Litoria adelaidensis	R	C			X	X	X		X			
L. moorei	R	C			X	X	X		X			
CHELUIDAE Side-necked Tortoises												
Chelodina oblonga	R	C			X	X	X		X	X	X	X
GEKKONIDAE Geckos												
Diplodactylus spinigerus	?	?	X	X								
Phyllodactylus m. marmoratus	R	M	X	X								
PYGOPODIDAE Legless Lizards												
Aprasia repens	R	M	X	X								
Delma fraseri	R	C	X	X		X						
D. grayii	R	U	X	X		X						
Lialis burtoni	R	C	X	X	X	X	X					
Pletholax g. gracilis	R	C	X	X								
Pygopus lepidopodus	R	U	X	X	X	X	X					
AGAMIDAE Dragon Lizards												
Pogona m. minor	R	C	X	X	X	X	X					
Tympanocryptis a. adelaidensis	R	U	X	X								
SCINCIDAE Skinks												
Cryptoblepharus plagiocephalus	R	C	X	X	X							X
Ctenotus fallens	R	U				X						
C. gemmula	?	?		X								
C. impar	R	U				X						

AMPHIBIAN and REPTILE	R	S	1	2	3	4	5	6	7	8	9	10
			HABITAT TYPE									
C. lesueurii	R	C	X									
Egernia kingii	R	?			X		X					
E. luctuosa	R	?			X		X					
E. napoleonis	R	M	X	X	X	X						
Hemiergis quadrilineata	R	U	X	X	X	X	X					X
Leiolopisma trilineatum	R	C			X	X	X					X
Lerista elegans	R	C	X	X	X	X						X
L. lineata 1	R	C	X	X		X						X
Menetia greyii	R	C	X	X	X	X						X
Morethia lineoocellata	R	U	X	X								
M. obscura	?	?			X	X						
Tiliqua occipitalis	R	R	X	X								
T. r. rugosa	R	C	X	X	X	X	X					X
VARANIDAE Monitors												
Varanus gouldii	R	U	X	X	X	X	X					X
V. rosenbergi	?	?	X	X	X	X	X					
V. t. tristis	R	R	X		X							
TYPHLOPIDAE Blind Snakes												
Ramphotyphlops australis	R	?	X	X	X	X						
BOIDAE Pythons												
Morelia spilota imbricata 1	?	G	X		X							
ELAPIDAE Elapid Snakes												
Demansia psammophis reticulata	R	U	X	X	X	X	X					
Notechis coronatus	R	U			X	X	X					
N. scutatus occidentalis	R	C			X	X	X	X	X			X
Pseudonaja a. affinis	R	C	X	X	X	X	X					X
Rhinoplocephalus gouldii	R	C	X	X	X	X						
Vermicella bertholdi	R	C	X	X								
V. bimaculata	?	M	X	X								
V. calonotos 1	R	U		X								
V. f. fasciolata	R	U		X								
V. semifasciata	R	U	X	X								

APPENDIX 2

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JANDAKOT GROUNDWATER SCHEME
STAGE 2

ENVIRONMENTAL CRITERIA STUDY GROUP

VOLUME 2

Aquatic Invertebrates Fauna and Water Quality

PART C

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September 1988

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1. INTRODUCTION

Williams (1983) defined wetlands in Australia as shallow sheets of standing water which exist for part or most of a year. Water is typically present during winter and spring, the wetland dries during summer and starts to refill in autumn. Light generally penetrates to the bed, water temperatures follow air temperatures and salinities gradually rise as water levels fall. Complex and diverse macrophyte communities are often present (these may extend across the entire wetland) and a seasonal succession of macrophytes often occurs.

The terms "wetland" and "lake" are used interchangeably in Perth however the term "lake" is usually considered to refer to deep and permanent bodies of freshwater. The shallow nature of standing waters on the Swan Coastal Plain (depth usually <3m) suggests that the term wetland is appropriate while the permanent nature of some also justifies the use of the term lake. However, the Northern Hemisphere concept of a lake is more closely approximated by the reservoirs of the Darling Scarp than the shallow standing waters of the coastal plain.

The wetlands of the Swan Coastal Plain are surface expressions of the underlying aquifer and water levels vary with the height of the water table. Because the region has a Mediterranean climate with cool wet winters and warm dry summers the wetlands experience a strongly seasonal hydrological cycle. Wetland water levels follow the pattern of rainfall but with a lag of approximately two months. Maximum depths occur in September and October and the lowest levels at the end of summer in March and April. The relative shallowness of all standing waters on the coastal plain makes it tempting to speculate that seasonal drying may have occurred in most wetlands in the past during extended dry periods. The urbanisation of the Perth region has led to changes in the nature of inputs to wetlands and many now receive a considerably greater proportion of their water from surface inputs than they did in the past. For some wetlands the quality of surface inputs may be poorer than desirable for the maintenance of aquatic ecosystems.

2. Why is it important to obtain information on the invertebrate communities of the wetlands of the Jandakot Mound?

Although a zoologist or conservationist would argue that it is important to obtain a knowledge of invertebrate communities for their own sake other arguments also exist. Firstly the invertebrate fauna represents an essential and significant component of wetland food webs. Aquatic invertebrates form the diet of many of the larger and more visible elements of the wetland fauna in particular the waterfowl and tortoises. A knowledge of the composition and structure of wetland invertebrate communities is essential to the understanding of the state of wetland food webs and the processes occurring within each wetland ecosystem. In addition to their importance in wetland food webs invertebrates can also be used as biological indicators of wetland water quality. A loss of species richness or diversity or changes in the presence or abundance of different trophic groups,for example, the predatory invertebrates, often reflects a deterioration in the water quality and overall environmental quality of the entire wetland. While measurement of physical and chemical parameters provides important instantaneous information on water quality the additional knowledge of the composition of invertebrate communities provides a direct assessment of the status of the aquatic biota.

3. The State of Knowledge of the Aquatic Invertebrate Fauna of Wetlands on the Jandakot Mound

The composition of the aquatic invertebrate communities of a small number of lakes on the Jandakot Mound has been recently recorded, on a seasonal basis, as part of a baseline chemical and biological monitoring programme for selected urban wetlands undertaken by the Wetland Ecology Group at Murdoch University for the Water Authority and the EPA. Data was collected over two years, from April 1985 to June 1987, for Thomsons Lake and North Lake and over a one year period, from June 1986 to May 1987, for Forrestdale Lake and Bibra Lake. The 1985/86 data set for Thomsons Lake and North Lake has been published in EPA Bulletin 265 (Davis and Rolls, 1987) and the 1986/87 data set is currently being prepared for publication as a further EPA Bulletin (Davis, Rolls and Balla, in prep.). Information on selected components of the fauna; the Odonata (dragonflies and damselflies) and the Coleoptera (water beetles) recorded at the four lakes between 1985 and 1987, and their role as indicators of environmental quality in wetlands, has also been published (Davis, Rolls and Balla, 1987).

Monitoring of the two indicator groups; the Odonata and the Coleoptera, has continued at Thomsons Lake, Forrestdale Lake and North Lake during 1987 and 1988 as part of an on-going biological and chemical monitoring programme of selected urban wetlands. This study is due for completion and reporting in November 1988.

Several studies have been undertaken on the problem of nuisance midges at Forrestdale Lake (Davis et al 1987, Balla et al 1987) and a recent report on investigations into more effective midge control in metropolitan wetlands includes information on the composition and abundance of chironomid populations in North Lake, Booragoon Lake and Forrestdale Lake over the summer of 1987/88 (Davis, Harrington and Pinder 1988).

Van Alphen (1983) documented differences in the flora and invertebrate fauna with season, salinity and drying in four lakes south of Perth, Forrestdale, Booragoon, Coogee Swamp and Lake Coogee, over a five month period in 1983 and Pinder (1986) studied changes in macroinvertebrate communities from summer drying to winter filling in Thomsons Lake and Forrestdale Lake over a six month period in 1986.

The macroinvertebrate fauna of Yangebup Lake was sampled by the students of Stream and Wetland Ecology at Murdoch University in 1987 and the species list obtained from this study was given in the Management Proposal for Yangebup Lake (SEM 1988).

4. Summary of Invertebrate Data

The list of species of aquatic invertebrates recorded at Thomsons Lake, Forrestdale Lake, North Lake and Bibra Lake during 1986/87 is given in Table 1 and represents the most comprehensive record of species occurring at these lakes compiled to date. A list of species recorded at Yangebup Lake in 1987 is given in Table 2. This list is less comprehensive than that compiled for the former four lakes because it represents species recorded on only one sampling occasion.

The two seasonal lakes, Thomsons and Forrestdale, contained a richer fauna than the two permanent lakes, North and Bibra, although species richness in North was also high (Figure 1). The number of species of two major groups of invertebrate predators, the Odonata and the Coleoptera, were higher in Thomsons and Forrestdale than in North and Bibra. Statistical analysis of the ten lake data set is presently being undertaken to determine if differences between lakes, on the basis of both water chemistry and invertebrate community structure, are significant but the analysis will not be completed in time for reporting here. However examination of the data provided in Figures 1 and 2 for lakes on both the Jandakot and Gnangara Mounds reveals that the seasonal lakes are generally richer in invertebrate species than the permanent water bodies and that the number of species of invertebrate predators in some of the permanent lakes is low. A reduction in the richness of the organisms at the top of invertebrate food chains, the predators, is considered to indicate a deterioration in the environmental quality of the waterbody. The reasons as to why the seasonal lakes may support a richer fauna than permanent lakes is at least partially related to the strongly seasonal hydrological regime experienced by the former which results in the presence of a greater variety of habitats, on both spatial and temporal scales. In addition water quality was generally better in the seasonal lakes than the permanent lakes (see the following section on water quality) and seasonal lakes are less likely to contain populations of the introduced mosquitofish, *Gambusia affinis*. This predatory fish is known to change the composition of invertebrate communities in water bodies where it occurs but it is usually excluded from lakes which dry over summer because it produces live young rather than resistant eggs. *G. affinis* may indirectly contribute to poor water quality through selective predation on larger zooplankton (which graze on algal blooms).

However it must also be noted that Thomsons Lake and Forrestdale Lake are located in the outer metropolitan region and as a consequence have been subject to fewer urban pressures than lakes such as North and Bibra. The deleterious effects of urban impacts on the structure and function of wetland ecosystems may be considerable and must not be underestimated.

Pinder (1986) noted that many of the invertebrates occurring in Perth wetlands are clearly adapted to cope with seasonal variations in water levels and the resulting physio-chemical changes either by means of their life history strategies or by their behaviour. Many species survive wetland drying by forming desiccation-resistant stages such as eggs or embryos. Some bury into the moist lake bed while others survive as flying adults and so possess the ability to re-colonize wetlands as they fill with winter rains. The exact nature of the strategies by which much of the invertebrate fauna of Perth wetlands copes with fluctuating water levels is not known. However a study is currently in progress to determine life history strategies of selected groups of the aquatic invertebrate fauna of Perth wetlands in response to fluctuating water levels and nutrient enrichment. This study is being undertaken as a PhD project by Shirley Balla under the supervision of Jenny Davis at Murdoch University and is jointly funded by AWRAC, EPA and the Water Authority. The major objective of this study is to provide biological information relevant to the determination of water level criteria for Perth wetlands.

5. Areas of Insufficient Information

No information is available on the invertebrate communities of wetlands in the Jandakot region other than the five listed above. In particular the lack of information on *Melaleuca* dominated tannin-stained lakes such as the Spectacles and Balannup Lake and the small ephemeral waterbodies (flooded paddocks) occurring on private land throughout the area represents a significant gap in our knowledge because preliminary site visits indicate that these systems are likely to be quite different to the four lakes which have been reasonably well studied. Both types of wetland are likely to be important to different species of waterfowl.

The problem of insufficient information on the invertebrate communities and water quality of wetlands of the Jandakot Mound will be largely overcome if a joint AWRAC/EPA/Water Authority project receives support as part of the AWRAC Partnership Research Program for a three year period from 1989 to 1991. The study entitled " Wetland Classification on the Basis of Water Quality and Invertebrate Community Data" would be jointly carried out by researchers at Murdoch University and the Water Authority. The objectives of the project are to

1) provide a classification and ranking of lakes on the basis of water quality data and aquatic biota

2) to elucidate statistical relationships between macroinvertebrate species assemblages and water quality data for predictive purposes

3) to design an on-going biological and chemical monitoring programme

and

4) to determine water quality criteria and design management strategies for the maintenance of aquatic food chains.

Seventeen lakes in the Jandakot region have been nominated for study: Brownman Swamp, Lake Mount Brown, Banganup Lake, Thomsons Lake, Yangebup Lake, Bibra Lake, North Lake, The Spectacles, Piney Lakes, Roe Swamp, Lake Kogolup, Mason Rd wetland, Banjup Lake, Bartram Rd wetland, Lake Coolongup, Forrestdale Lake and Balannup Lake.

6. The State of Knowledge of Water Quality of Wetlands on the Jandakot Mound

Seasonal changes in water quality of Thomsons Lake, Forrestdale Lake, North Lake and Bibra Lake has been recorded as part of the biological and chemical monitoring programmes of selected urban wetlands mentioned above in the discussion of invertebrate communities (Davis and Rolls, 1987; Davis, Rolls and Balla, in prep). The major physical and chemical data sets obtained in this study over the two year period 1985 to 1987 are given in Figures 3-14. A long term water quality monitoring programme of 21 urban wetlands has been undertaken by the Water Authority from 1970 to 1986 and included twice yearly measurements (in February-March and September-October) of various physio-chemical parameters in the following lakes which lie south of the Swan River; Bibra, Blue Gum, Booragoon, Coogee, Forrestdale, North, Richmond, Cooloongup and Yangebup. Some of the major results of this study have been analysed and discussed as a student project undertaken at Murdoch University and are currently being prepared for publication subject to Water Authority approval (Robson and Davis, in prep) Arnold (in prep) has provided a summary of the water quality data available for the following lakes in the Jandakot region; North Lake and Roe Swamp, Bibra Lake, Yangebup Lake, Thomsons Lake, Lake Banganup, Wattleup wetlands, The Spectacles and Bollard Bullrush Swamp. Water quality data for selected lakes were also given in the following studies: Newman and Hart (1984) for North Lake, Bibra Lake, Bibra Swamp and Murdoch Swamp, Newman et al (1976) for the Cockburn wetlands which included North, Bibra, Yangebup and Thomsons, Murdoch University (1986) for North Lake, Students of N319 Environmental Management (1987) for Yangebup Lake.

7. Summary of Water Quality Data

The results of the 1985/87 data set collected by the Wetland Ecology group at Murdoch University are summarised below.

1. Monthly (1985/86) and subsequent two monthly (1986/86) sampling of water chemistry of four lakes on the Jandakot Mound revealed that the two seasonal lakes, Thomsons and Forrestdale, showed highly seasonal changes in conductivity with very high levels being recorded just prior to drying. In contrast North and Bibra were fresher and displayed much lower summer maxima.

2. All lakes were enriched on the basis of total phosphorus concentrations; levels in Bibra were exceptionally high while Thomsons was the only lake to fall below the level considered to indicate eutrophication for part of each year.

3. Levels of chlorophyll a were higher in the two permanent lakes, North and Bibra, than in the two seasonal lakes, Thomsons and Forrestdale. Levels in excess of 200ug/l appeared to promote chironomid production at nuisance levels. The three lakes at which these levels or greater were recorded; Bibra, North and Forrestdale, also experienced nuisance midge swarms during the summer months.

4. Levels of ammonium and nitrate/nitrite were very high at Bibra and North Lake in comparison to the levels recorded at Thomsons and Forrestdale.

8. Areas of Insufficient Information

No information is available on the water quality of wetlands in the Jandakot region other than for those listed above; North, Bibra, Yangebup,Thomsons and Forrestdale. Similar to the statement made concerning the invertebrate fauna the lack of information on the *Melaleuca* - dominated tannin-stained lakes such as the Spectacles and Balannup Lake and the small ephemeral waterbodies (flooded paddocks) occurring on private land throughout the area represents a significant gap in our knowledge because preliminary site visits indicate that these systems are likely to be quite different to the lakes which have been reasonably well monitored.

9. Information Relevant to the Setting of Interim Environmental Criteria for Wetland Water Levels on the Jandakot Mound

1. The Mediterranean climate and marked seasonal hydrological cycle naturally experienced by wetlands in the Jandakot region indicates that seasonal variation in water level should be a feature of a managed system. Annual water level changes of approximately 1m have been recorded in most wetlands and changes of up to 1.5 or 2m may occur in some wetlands. The fauna appears to have the capacity to cope with the relatively gradual seasonal changes. The effects of sudden changes in water level are not known but are likely to be undesirable, for example, sudden drying would result in a massive die-off of much of the aquatic fauna and this would be accompanied by the attendant problems of the decay and decomposition of large amounts of organic material.

2. Data summarised in this report is considered to indicate that seasonal drying may be a preferred management option for some wetlands on the Jandakot mound. Seasonal drying appears to enhance invertebrate diversity and Maher (1984) in a NSW study suggested that the peaks of organic matter which occur after reflooding promote invertebrate and waterfowl productivity.The question as to whether seasonal drying may ameliorate some of the effects of nutrient enrichment in Perth wetlands is as yet unresolved. The AWRAC/WAWA/EPA project recently started by Balla and Davis should provide some answers to this question. The problems of poor water quality experienced in some permanent waterbodies in the Perth region may be a consequence of the fact that they are algal-dominated rather than macrophyte-dominated systems. Shallow wetlands such as Thomsons Lake and Forrestdale Lake contain extensive beds of macrophytes such as *Myriophyllum*, *Potamogeton* and *Ruppia*. Nutrients are removed from the water column by these species and the length of time involved in the cycling of nutrients between the bed, aquatic plant material and the water column is likely to be longer than that for an algal-dominated system. A substantial increase in depth,for example, an additional metre of water or more, may mean that suitable conditions for the growth of these species (which are depth and light-limited) no longer exist. As a result algal species may become dominant if waters are enriched and such systems generally experience greater water quality problems. For example, the occurrence of massive algal blooms and their subsequent decay may result in offensive odours, fish kills and bird deaths. The cycling of nutrients between the water column and the lake bed is likely to be quicker, particularly if blue-green species are dominant, and so the probability of blooms recurring is enhanced. Decaying algal blooms also appear to provide a readily available food source for larval midges, as a consequence midge populations become larger and the problems experienced with nuisance midges in nearby suburbs is likely to be greater.

3. The shallow nature of many of the wetlands on the Swan Coastal Plain indicates that too much water (i.e. too great an increase in depth which occurs as a consequence of increased urban run-off) and the loss of seasonality of hydrological regimes may result in undesirable ecological effects of nearly equal magnitude to the problem of wetland loss because of a lowered water table. In particular, problems arise when the increase in surface run-off results in large quantities of poor quality water entering a wetland.

4. Temperature/oxygen profiles recorded from dredged waterbodies in Herdsman Lake indicate that problems of stratification will arise if wetlands are deepened beyond 5m. Water quality problems will inevitably result if the waters are excessively enriched. Problems may be avoided by employing management strategies such as the artificial aeration of bottom waters however such strategies may be costly.

5. Although it is difficult to predict the actual consequences of increasing or decreasing the depth of a particular lake by 1m or more because of the complexity of biological processes involved and of which we do not as yet have a good scientific knowledge, some general comments can be made. The shallow nature of Thomsons Lake and Forrestdale Lake (maximum depth 1-1.5m) in recent years indicates that these lakes could not tolerate a further decrease of 1m without the lakes having too little water to support aquatic life for most of the year. An increase in maximum depth of 1m would mean that seasonal drying of the lake bed beyond the margin of the fringing vegetation may not occur. As a consequence their value as habitats for wading birds would be lost. Some of the fringing vegetation may die, which in the case of the bulrush, *Typha orientalis*, may be considered to be a beneficial result. The lakes may become algal-dominated if conditions are no longer suitable for macrophyte growth and problems with poor water quality may increase as a result. Introduced fish, in particular the mosquitofish, and possibly carp, are likely to become well established at both lakes, which may indirectly contribute to water quality problems. Neither fish are presently established at either lake.

6. Because plant communities are central to all wetland processes decisions regarding water level changes must be made firstly with a knowledge of how these changes will affect the dominant plant communities. Changes in both submerged and emergent plant communities will affect all other components of wetland food webs. Knowledge of the ways in which water quantity may also affect water quality is also needed.

7. The construction of a channel running from north to south in association with the Beeliar chain of wetlands may be a useful means for manipulating wetland water levels but care must be taken to ensure that poor quality water from the inner urban region does not arrive at less enriched wetlands on the outer perimeter of the Jandakot mound.

8. Lack of knowledge of the physical, chemical and biological changes that may result when wetland water levels are altered beyond the range associated with seasonal fluctuations (as recorded in recent years) indicates that a monitoring programmme should be undertaken at a representative sample of lakes where water level changes are proposed and at lakes where no changes other than natural i.e. climatically induced changes are anticipated. In this way the present problem of trying to predict the consequences of water level changes from an inadequate information base could be avoided in future years. In addition undesirable effects occurring as a result of water level changes may be detected reasonably quickly and remedial action may be effectively implemented.

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Table 1. List of species recorded at four wetlands on the Jandakot Mound between June 1986 and May 1987.

ORDER	FAMILY		WETLAND North	Bibra	Thomsons	Forrestdale
		Nematoda				
		Oligochaeta	•	•	•	•
Hirudinea	Glossiphonidae	Glossiphonid spp.	•	•	•	•
Bivalvia	Sphaeriidae	*Pisidium sp.*				
		Ferrissia sp.				
Gastropoda	Planorbidae	*Physastra georgiana*	•		•	•
		Helisoma duryi *	•			
	Lymnaeidae	*Lymnaea columella* *				
	Physidae	*Physa acuta*	•	•	•	•
Ostracoda		*Mytilocypris ambiguosa*			•	•
		Sarscypridopsis aculeata		•	•	•
		Candonocypris novae-zelandiae	•	•	•	•
		Eucypris virens				•
		Cypretta baylyi	•	•	•	•
		Bennelongia australis	•		•	•
		Alboa worooa			•	•
		Diacypris spinosa				•
		Ilyocypris australiensis				•
		Ostracod sp.A	•		•	
		Gomphodella sp. 1			•	
		Ostracod sp.C		•	•	
		Ostracod sp.D	•		•	
		Ostracod sp.E				
		Ostracod sp.F	•			•
		Ostracod sp.G	•			•
		Ostracod sp.I	•			
Copepoda	Calanoida	Calanoid	•	•	•	•
	Cyclopoida	Cyclopoid	•	•	•	•
	Harpacticoida	Harpacticoid	•			
Cladocera	Chydoridae	Chydoridae			•	
	Macrothricidae	Macrothricidae			•	•
	Moinidae	Moinidae			•	
	Daphniidae	*Daphnia sp.*	•	•	•	•
		Ceriodaphnia sp.			•	•
Isopoda	Phreatoicidae	*Paramphisopus palustris*	•		•	•
Amphipoda	Ceinidae	*Austrochiltonia subtenius*	•	•	•	•
Decapoda	Palaemonidae	*Palaemonetes australis*				
Acarina	Hydracarina	*Limnochares australica*	•		•	•
		Acercella falcipes	•	•	•	•
		Acercella sp.1	•	•	•	
		Piona cumberlandis	•		•	
		Piona australis ?	•	•		
		Piona sp.1			•	
		Arrenurus balladoniensis	•			
		Arrenurus sp.1	•			
		Arrenurus sp.2				
		Limnesia sp.1		•	•	•
		Eylais sp.1	•	•	•	•
		Hydrachna sp.1	•	•		•
		Hydracarina sp. S				
		Hydracarina sp. T		•		•
		Hydracarina sp. U	•			
		Hydracarina sp. V	•			
		Trombidioidea				
		Mesostigmata			•	
	Orabatidae	*Orabatid sp.1*			•	
Ephemeroptera	Leptophlebiidae	*Atalonella sp.1*				
	Baetidae	*Cloen sp.1*				
	Caenidae	*Tasmanocoenis sp.1*	•			
		Ephemeroptera juv.				
Odonata	Aeschnidae	*Hemianax papuensis*		•	•	•
		Aeshna brevistyla			•	
		Procordulia affinis			•	
	Corduliidae	*Hemicordulia tau*			•	
	Libellulidae	*Diplacodes bipunctata*			•	
		Anisoptera juv.			•	
		Argiolestes pusillus			•	
	Coenagrionidae	*Xanthagrion erythroneurum*	•	•	•	•
		Ischnura aurora	•		•	•
	Lestidae	*Austrolestes annulosus*	•	•	•	•
		Austrolestes leda				•
		Austrolestes analis	•		•	
		Austrolestes io			•	
		Damsel juv.	•	•		•
Hemiptera	Corixidae	*Micronecta robusta*	•	•	•	•
		Agraptocorixa hirtifrons	•	•		•
		Sigara mullaka	•	•	•	•
		Diaprepocoris sp.1				
		Corixid juv.	•	•	•	•
	Notonectidae	*Anisops thienemanni*	•	•		•
		Anisops gratus		•		•
		Anisops spp.	•	•	•	
		Nychia spp.	•	•	•	•
		Nychia juv.	•	•	•	•
		Notonectid juv.			•	
	Nepidae	*Ranatra sp.1*				
		Veliidae sp.1			•	
	Veliidae	*Mesovelia spp.*	•		•	
		Microvelia spp.				
Diptera	Chironomidae	*Chironomus australis*	•	•		
		Chironomus alternans	•	•	•	
		Chironomus curdvalva				
		Chironomus annulivenlris			•	•
		Chironomus martini				
		Cryptochironomus griseidorsum				
		Cricotopus albiabla			•	
		Dicrotendipes conjunctus	•	•	•	•
		Polypedilum nubifer	•	•		•
		Corynoneura sp.1				
		Tanytarsus fuscithorax				
		Lundstroemia parthenogenetica			•	
		Procladius villosimanus	•	•	•	•
		Paramerina levidensis		•	•	•
		Lymnophyes pullulus	•	•	•	•
		Tanypod sp.V10				•

Table 1.

	Ceratopogonidae	Ceratopogonidae sp.A				
		Ceratopogonidae sp.B			+	
		Ceratopogonidae sp.C			+	
		Ceratopogonidae sp.D				
		Ceratopogonidae sp.E				
		Ceratopogonidae sp.F				+
	Tipulidae	Tipulid sp.2				
	Thaumaleidae	Thaumaleidae sp.1				
	Culicidae	Culicinae sp.1			+	+
		Chaoborinae sp.1			+	
	Tabanidae	Tabanid sp.1			+	+
	Stratiomyidae	Stratiomyid sp.1	+		+	+
Lepidoptera	Pyralidae	Lepidoptera sp.1			+	+
Trichoptera		*Triplectides australis*	+	+	+	+
		Notalina fulva			+	
		Oecetis sp.1	+		+	
	Ecnomidae	*Ecnomus pansus*	+			
		Ecnomus turgidis	+			
	Hydroptilidae	*Hellyethira litua*			+	
		Hydroptilid juv.			+	
		Hydroptilid sp.1				
		Trichoptera juv.	+			+
Coleoptera	Dytiscidae	*Cybister? tripunctatus*			+	
		Cybister sp.2				
		Cybister? sp.3				+
		Lancetes lanceolatus				+
		Sternopriscus multimaculatus				
		Sternopriscus minimus				
		Sternopriscus sp.2				
		Megaporus solidus			+	
		Megaporus sp.1	+	+	+	
		Hyphydrus sp.1	+	+		+
		Hyphydrus sp.2		+		
		Dytiscid sp.1				
		Dytiscid sp.2			+	
		Dytiscid sp.3				
		Antiporus sp.1				
		Liodessus sp.1			+	
	Hydrophilidae	*Berosus discolor*				
		Berosus sp.1			+	+
		Berosus sp.2				+
		Berosus sp.3				+
		Helochares sp.1	+			
		Paracymus pygmaeus (?)	+		+	+
		Hydrophilid sp.1	+	+	+	+
		Hydrophilid sp.2				
		Enochrus sp.1			+	+
	Hygrobiidae	*Hygrobius sp.1*	+			
	Haliplidae	*Haliplus fuscatus/globus*			+	+
		Haliplus sp.1				+
	Hydrochinae	*Hydrochus sp.1*				
		Hydrochus sp.2				
		Hydrochus sp.3			+	
	Helodidae	Helodid sp.1				
	Curculionidae	Curculionid sp.1			+	+
		Curculionid sp.2				
		Curculionid sp.3				
	Scirtidae	*Scirtes(?) sp.1*			+	+
	Hydraenidae	*Hydraena sp.1*				

Table 2. List of species recorded at Yangebup Lake in August 1987.

Nematoda

Nematode sp.

Arthropoda

Arachnida
Order Acarina
Acercella falcipes
Eylais sp.

Crustacea

Subclass Ostracoda
Candonocypris novaezelandiae
Sarscypridopsis aculeata
Ostracod sp.

Subclass Copepoda
Order Cyclopoida
Cyclopoid sp.

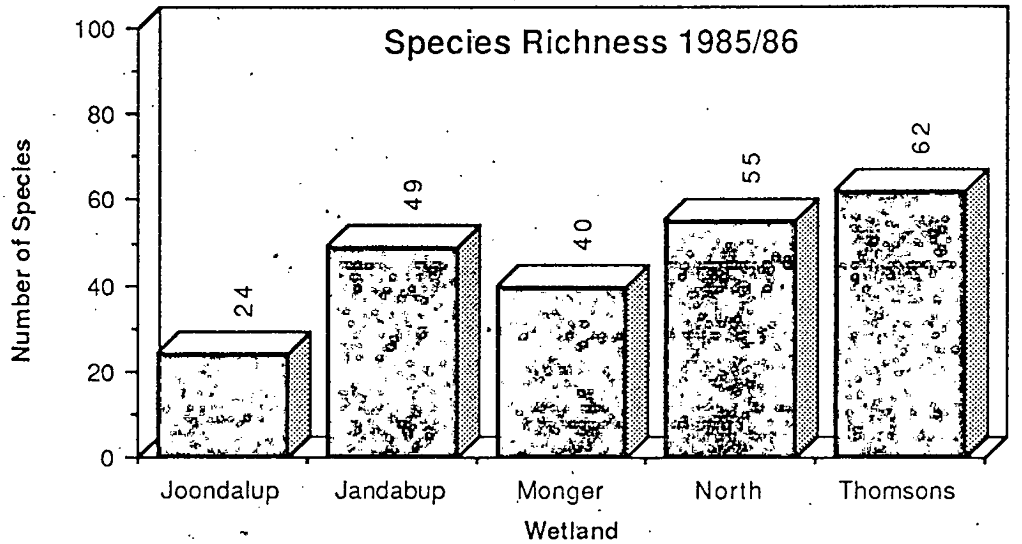
Insecta

Order Diptera
Family Ceratopogonidae
Ceratopogonid sp.
Family Chironomidae
Chironomus australis
Polypedilum nubifer
Procladius villosimanus

Order Hemiptera
Family Corixidae
Agraptocorixa hirtifrons
Micronecta robusta
Family Notonectidae
Anisops sp.
Order Odonata
Zygoptera sp.
Order Trichoptera
Triplectides australis

Mollusca

Mollusc sp.



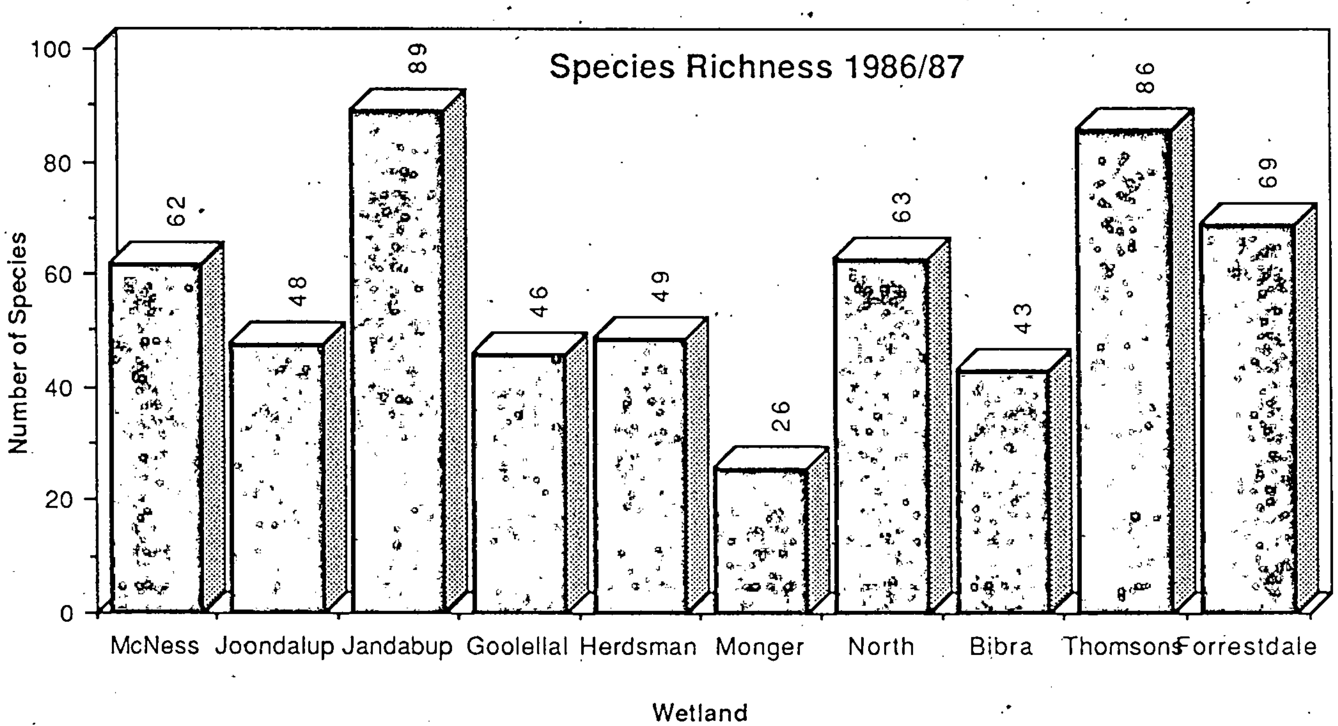


Figure 1. Total species richness recorded at five urban lakes in 1985/86 and ten urban lakes in 1986/87.

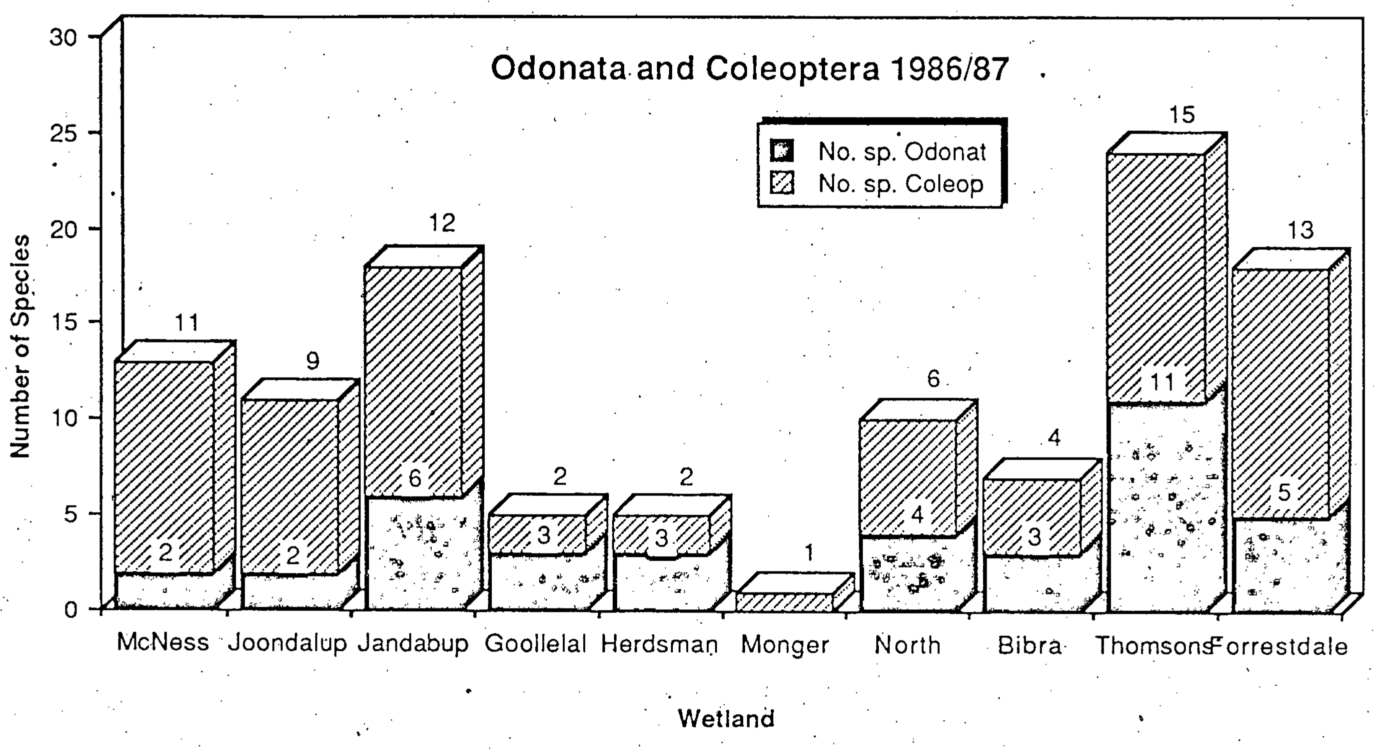


Figure 2. The total number of species of Odonata and Coleoptera recorded at ten urban lakes in 1986/87.

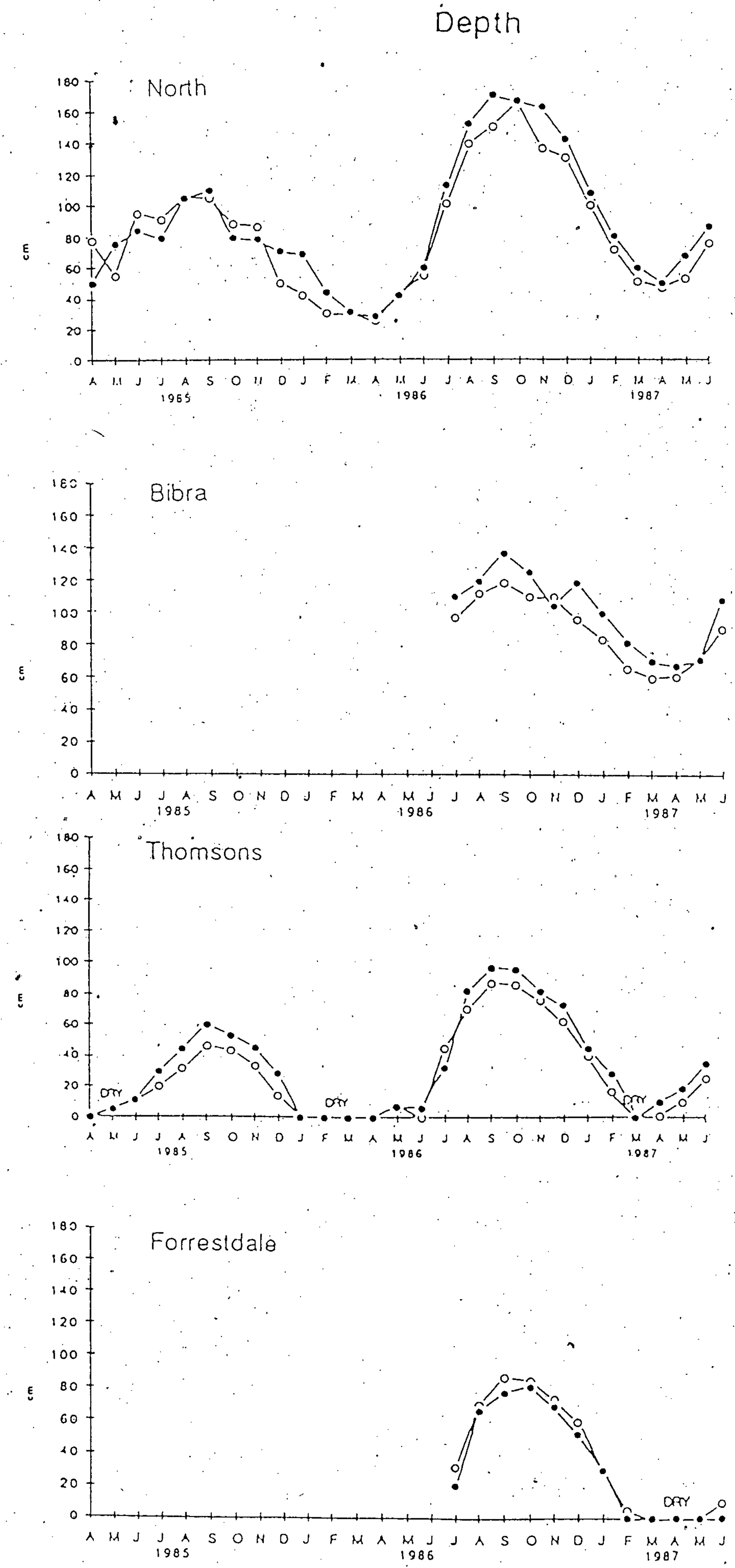


Figure 3. Changes in depth recorded at two sites in four lakes on the Jandakot Mound between 1985 and 1987.

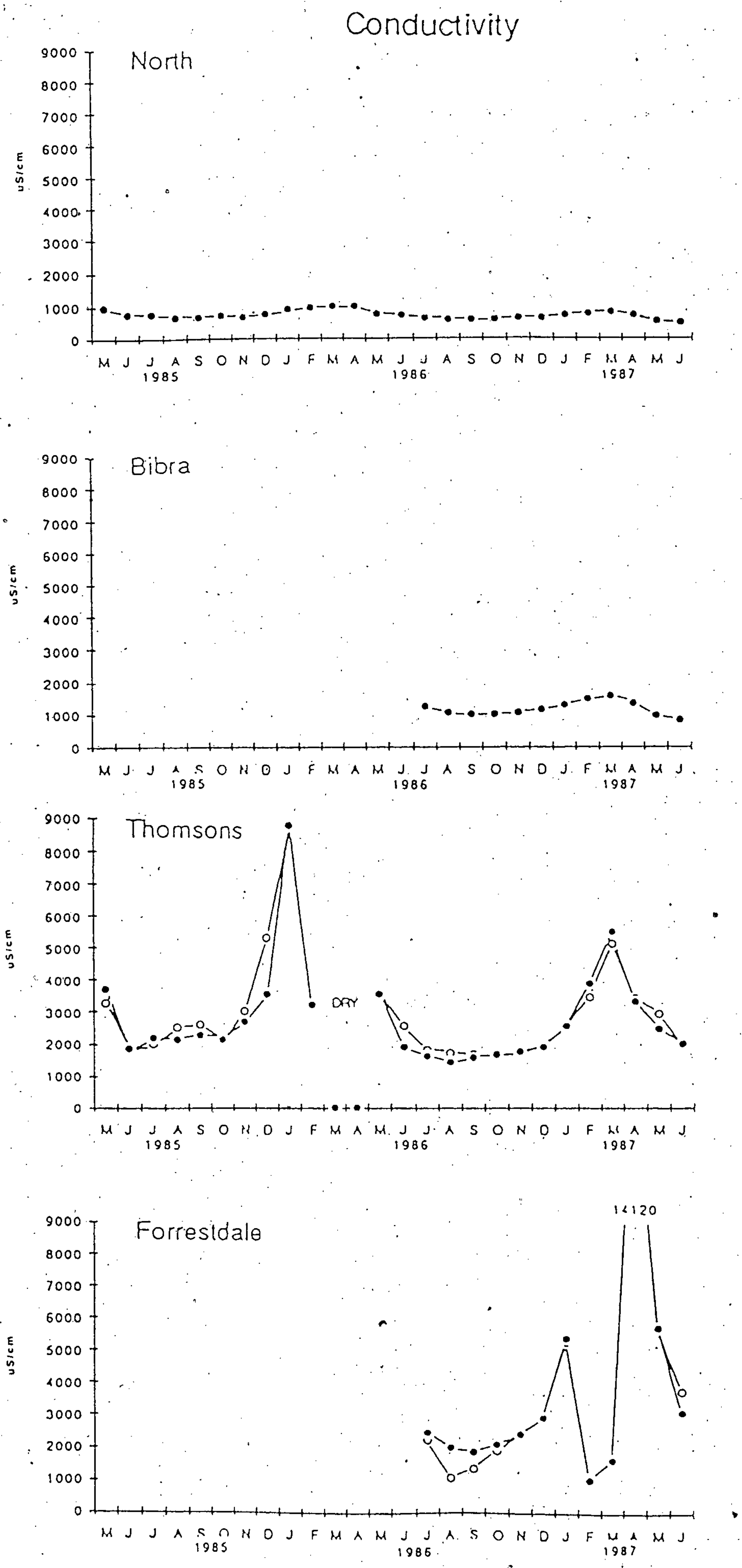


Figure 4. Changes in conductivity recorded at two sites in four lakes on the Jandakot Mound between 1985 and1987.

pH

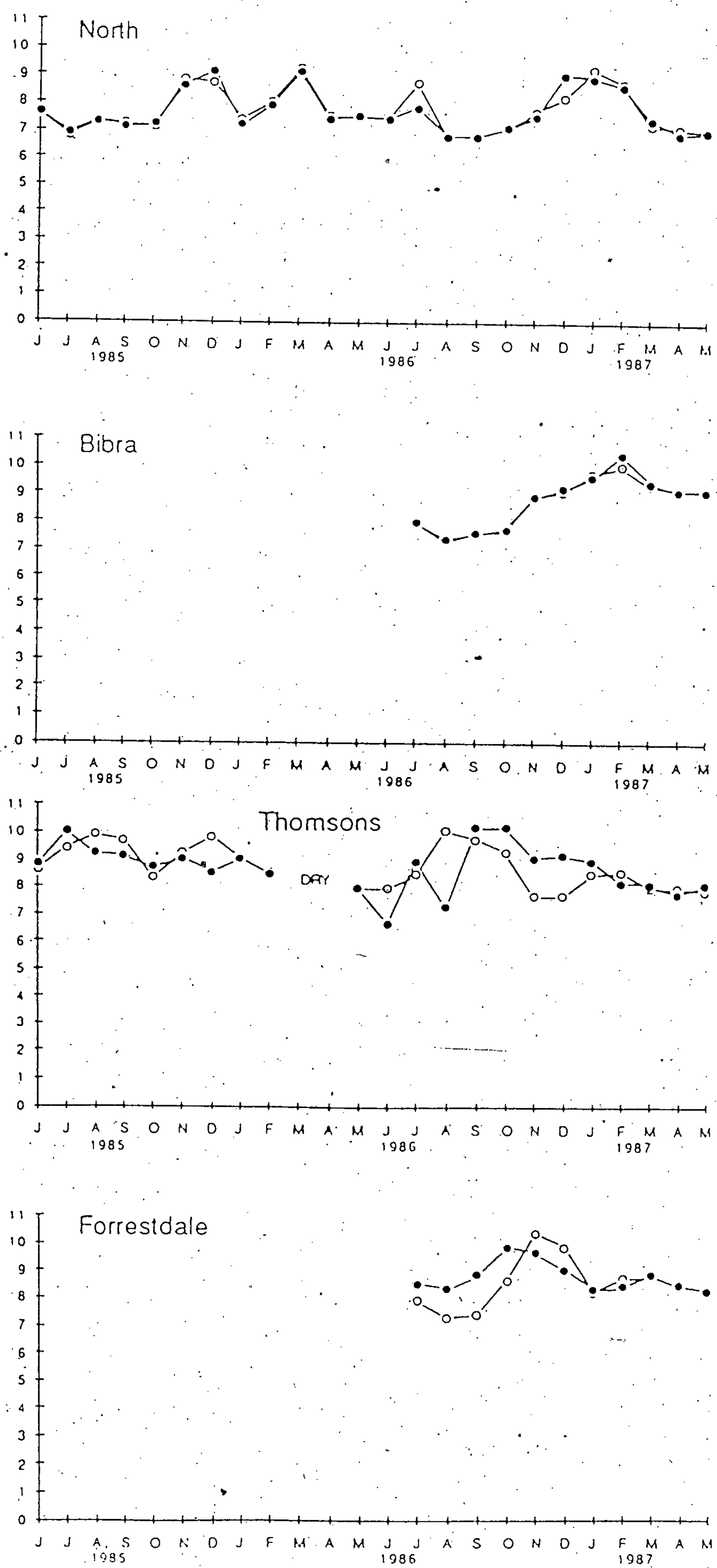


Figure 5. Changes in pH recorded at two sites in four lakes on the Jandakot Mound between 1985 and 1987.

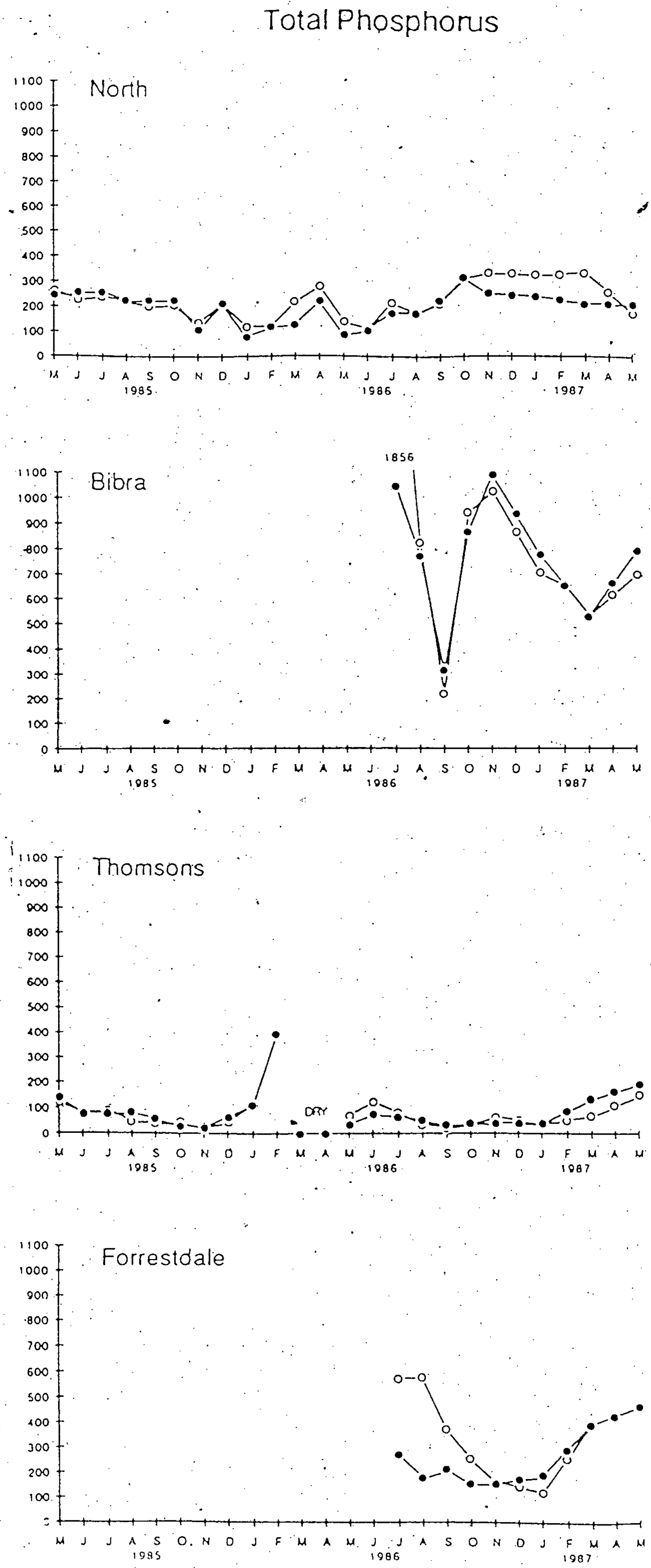


Figure 6. Changes in total phosphorus concentration (in micrograms/litre) recorded at two sites in four lakes on the Jandakot Mound between 1985 and 1987.

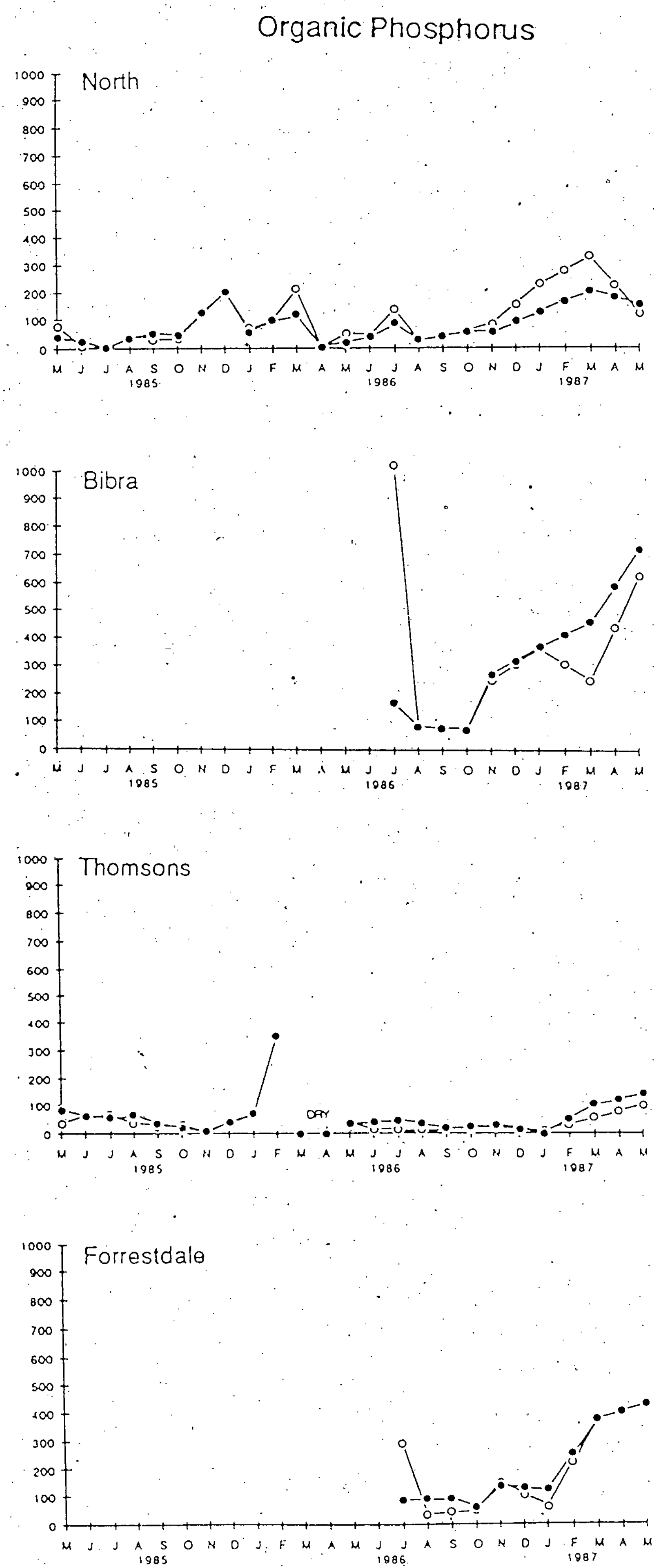


Figure 7. Changes in organic phosphorus concentration (in micrograms/litre) recorded at two sites in four lakes on the Jandakot Mound between 1985 and 1987.

Orthophosphate (PO_4)

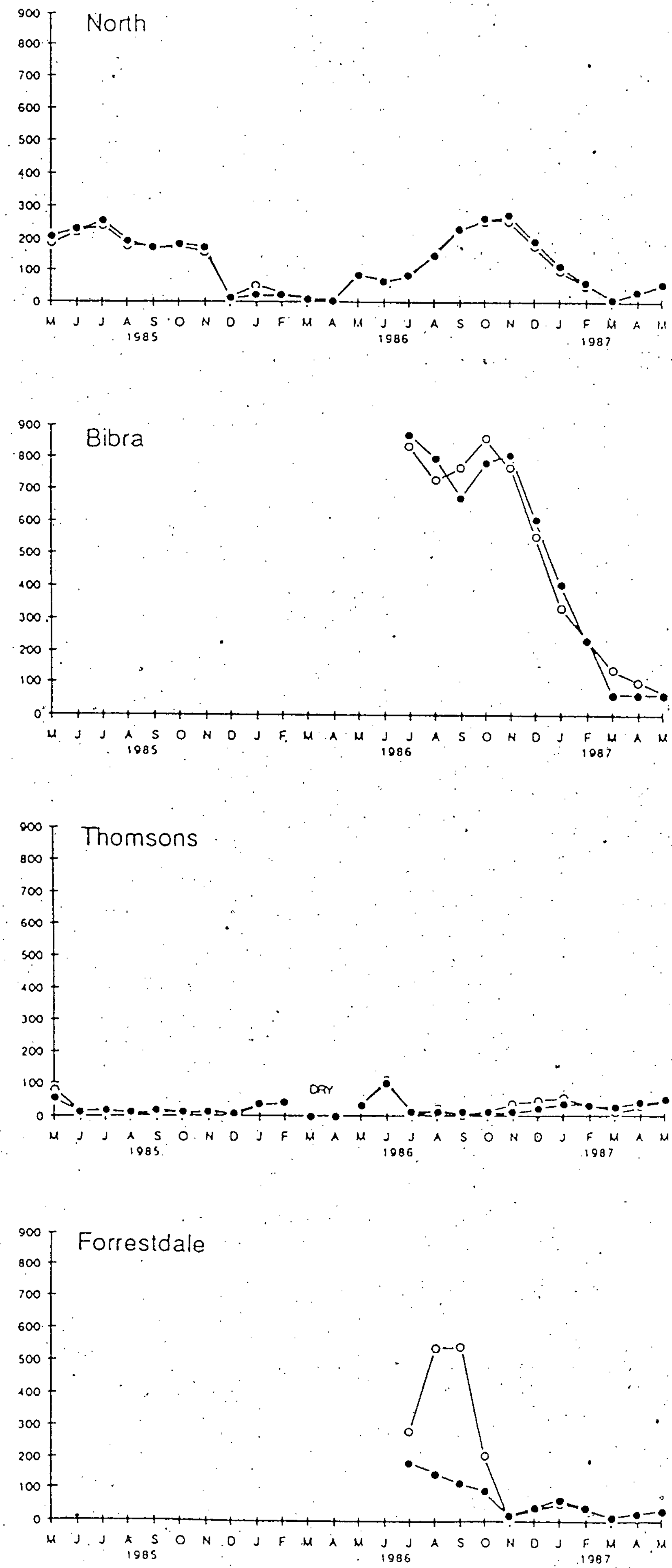


Figure 8. Changes in orthophosphate concentration (in micrograms/litre) recorded at two sites in four lakes on the Jandakot Mound between 1985 and 1987.

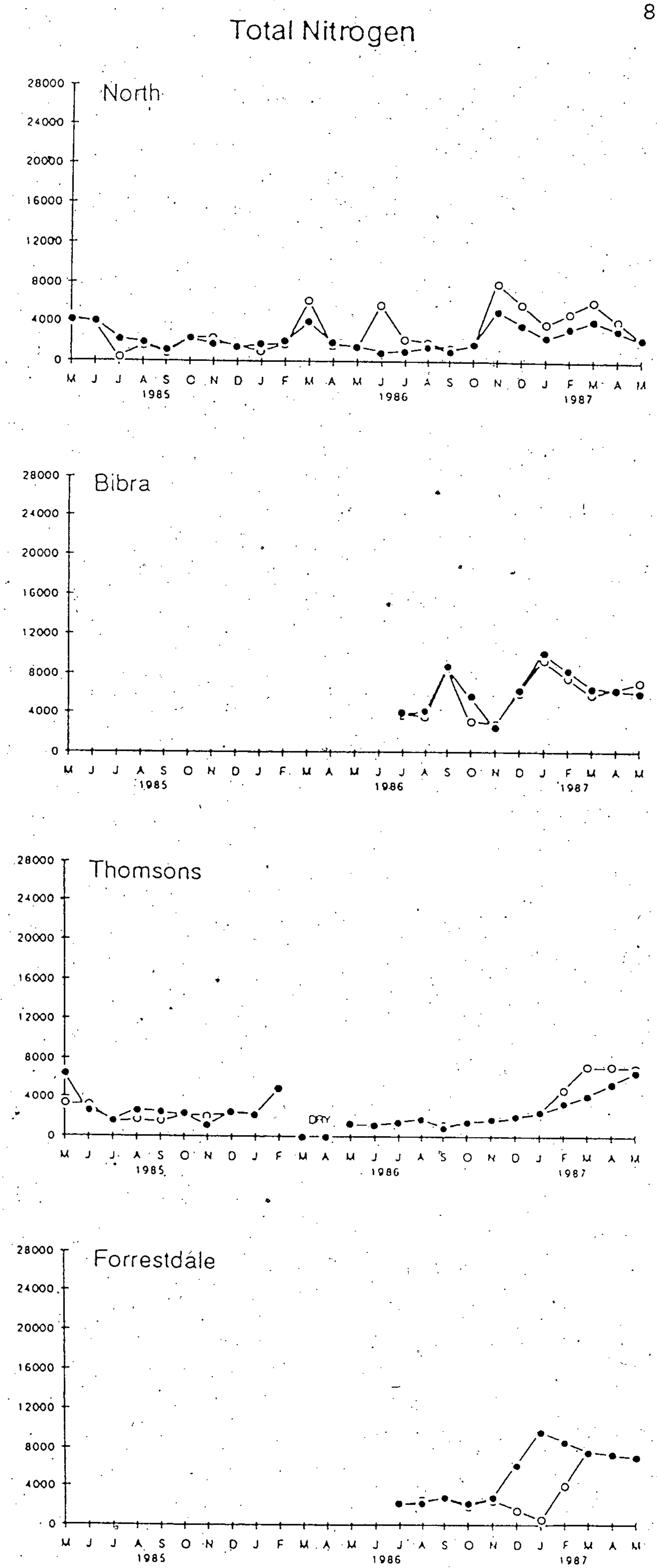


Figure 9. Changes in total nitrogen concentration (in micrograms/litre) recorded at two site in four lakes on the Jandakot Mound between 1985 and 1987.

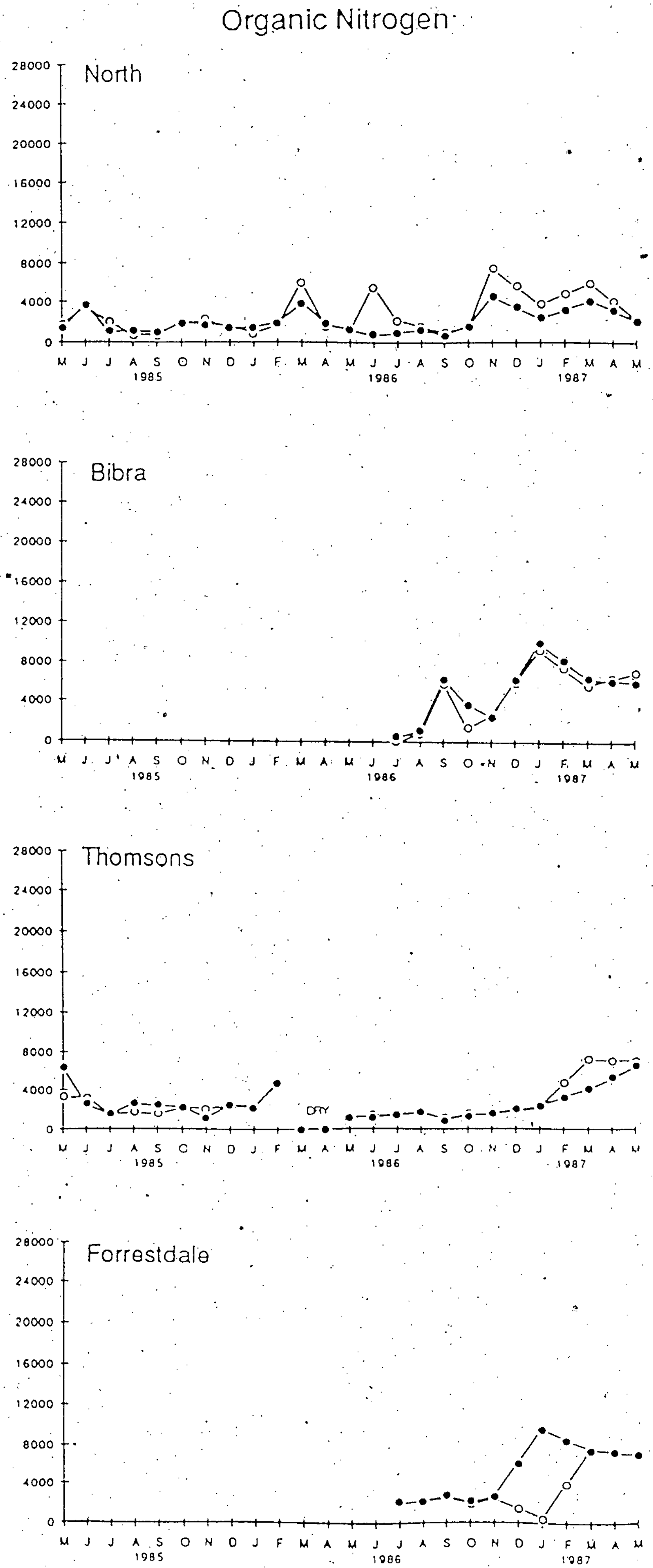


Figure 10. Changes in organic nitrogen concentration (in micrograms/litre) recorded at two sites in four lakes on theJandakot Mound between 1985 and 1987.

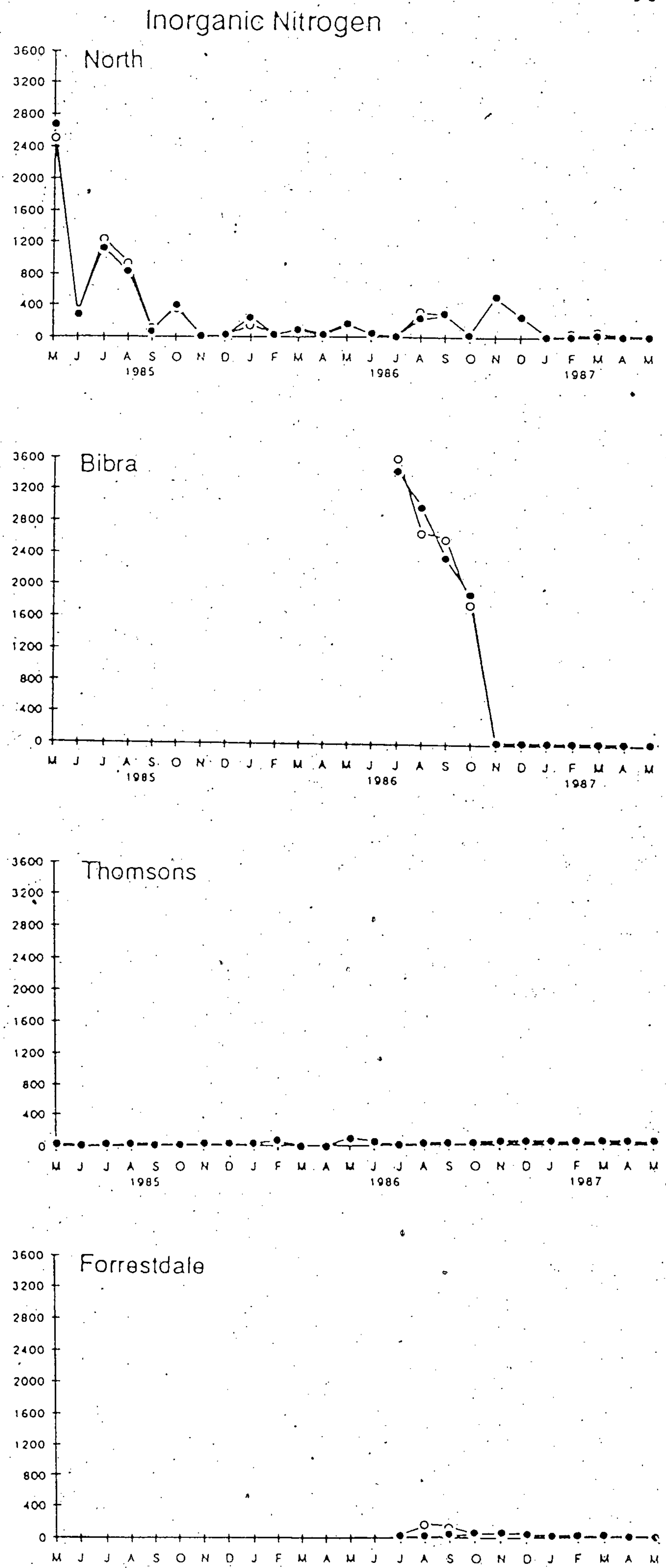


Figure 11. Changes in inorganic nitrogen concentration (in micrograms/litre) recorded at two sites in four lakes on the Jandakot Mound between 1985 and 1987.

Ammonia (NH_4)

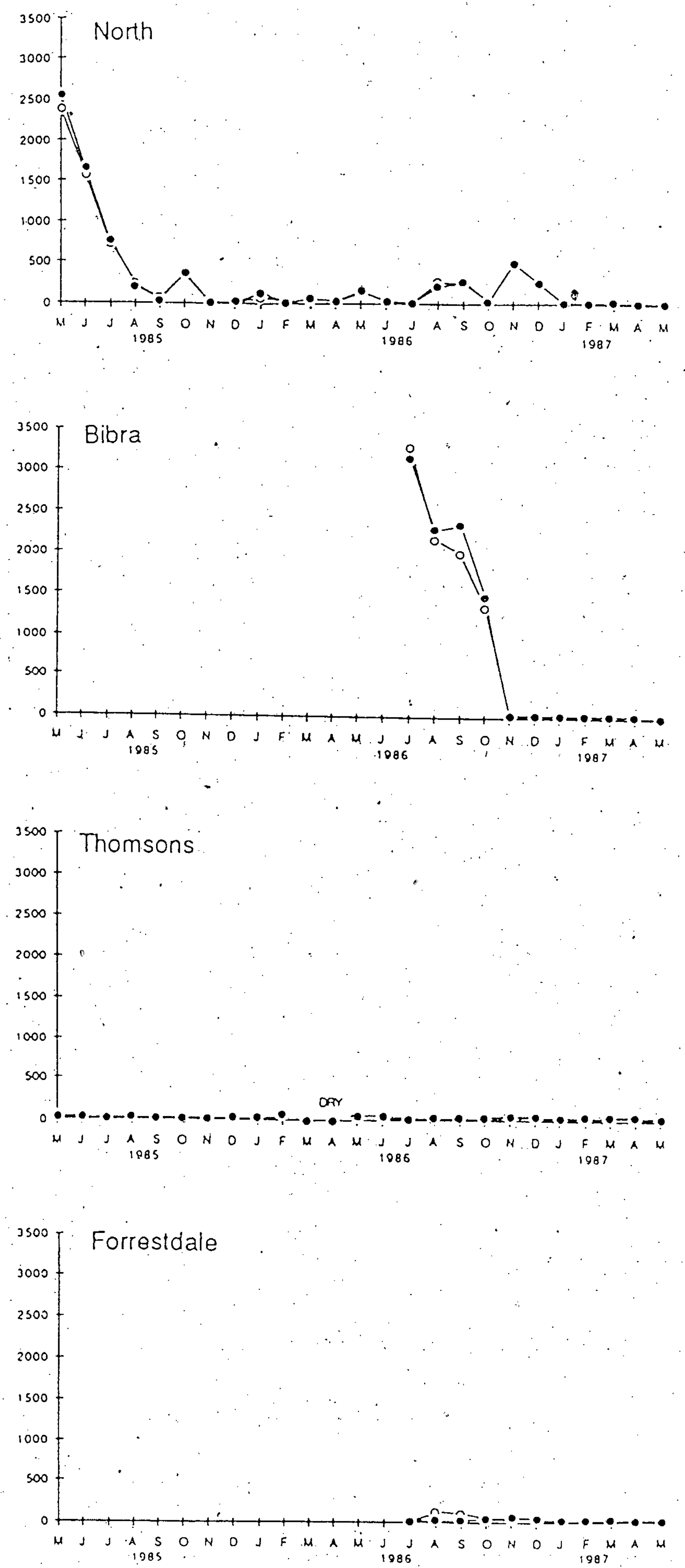


Figure 12. Changes in ammonium concentration (in micrograms/litre) recorded at two sites in four lakes on the Jandakot Mound between 1985 and 1987.

Nitrite - Nitrate (NO_2 / NO_3)

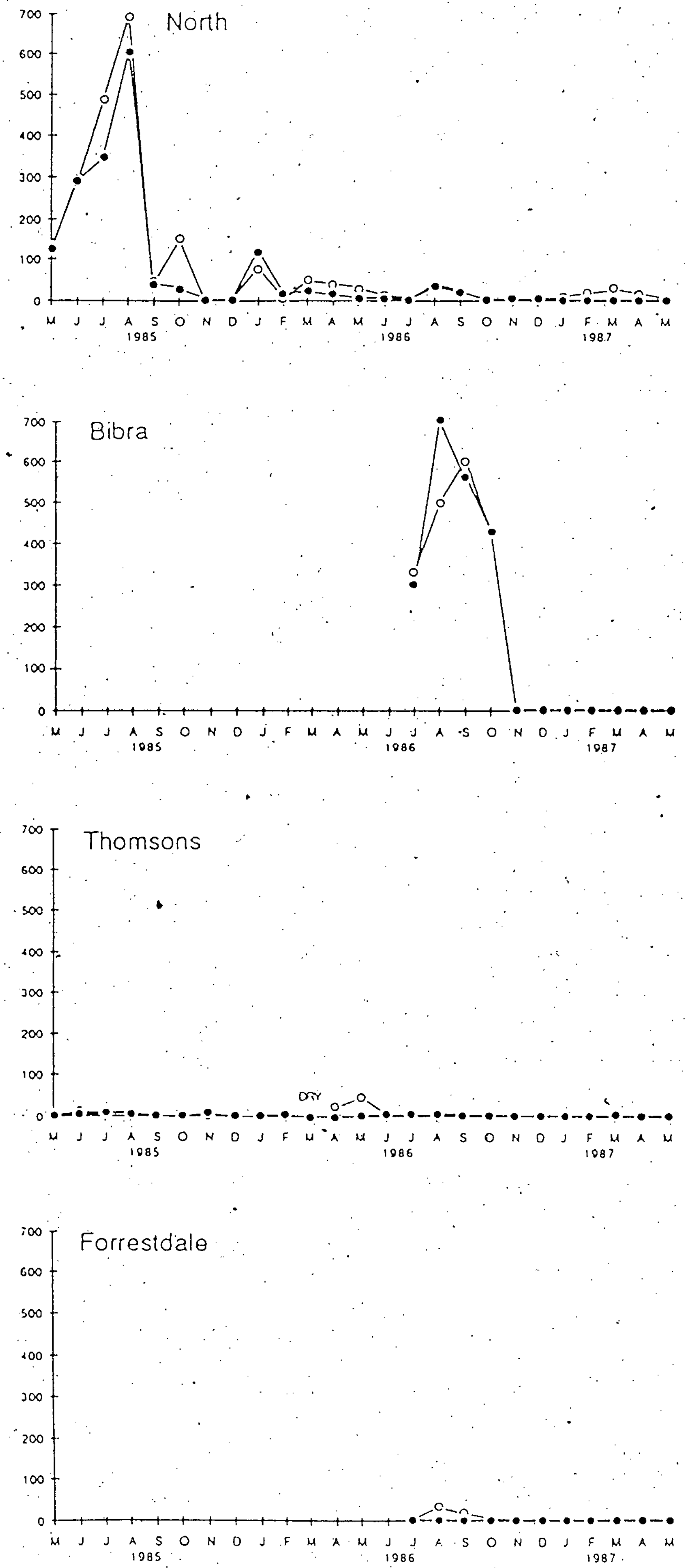


Figure 13. Changes in nitrite-nitrate concentration (in micrograms/litre) recorded at two sites in four lakes on the Jandakot Mound between 1985 and 1987.

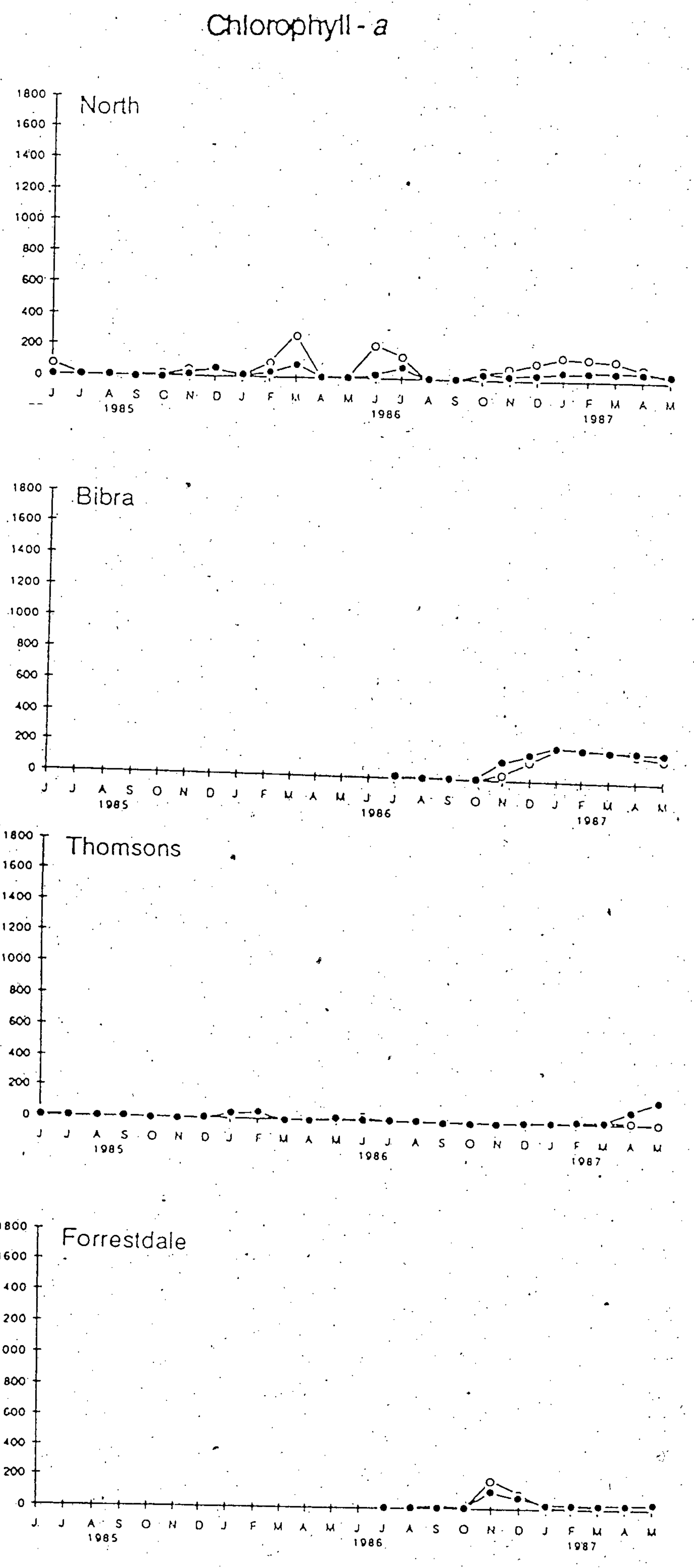


Figure 14. Changes in chlorophyll *a* concentration (in micrograms/litre) recorded at two sites in four lakes on the Jandakot Mound between 1985 and 1987.

JANDAKOT GROUNDWATER SCHEME STAGE 2

ENVIRONMENTAL CRITERIA STUDY GROUP

VOLUME 2

Social Criteria for the Management of Wetlands

PART D

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Prepared by: G J Syme & D K MacPherson

September 1988

CONTENTS

SUMMARY

This report is concerned with community-based procedures and reasoning by which water levels and water quality indices are declared satisfactory or unsatisfactory.

In the past in Western Australia there has been some reference to social factors such as cultural interests and recreational needs but there has been little use of social judgement of the desirability of particular water levels or qualities.

While it would be convenient to establish general, stable criteria for the management of wetlands, this is impossible given the idiosyncratic historical and social context of the development of community perceptions. Expectations of wetlands management vary from place to place and also from time to time.

We suggest that socially based criteria in relation to wetlands are derived from social expectations which in turn are a product of community values, attitudes and behaviours.

On the basis of our work in Jandakot we distinguish three important dimensions of local values, attitudes and behaviour: aesthetic, altruistic/conservation, and personal well-being. These social dimensions are examined on three spatial scales: regional, local and the immediate neighbourhood.

Aesthetic judgements of wetlands for planning purposes have been usually made by experts with ecological or formal-aesthetic models. There are, however, numerous techniques which can reliably elicit landscape preferences from members of the community.

International literature based on these techniques suggest that bodies of open water are the dominant factors governing aesthetic appreciation of particular landscapes. We interpret this to say that noticeable losses in the surface area of open water in wetlands will be disliked by the community. It also suggests that drainage water could be usefully aggregated to create aesthetically pleasing artificial ponds.

This assessment is generally consistent with the views of local residents that we surveyed, who expected aesthetic criteria to:

(a) preserve landscape aesthetics associated with open water,

(b) allow clearing of bush in such a way as to maintain views of lakes, but not so as to disadvantage wildlife,

(c) maintain high water levels unless there was some clear reason to the contrary

(d) use any opportunities provided by drainage to create open bodies of water.

There is a need for research to understand more precisely how much average or extreme levels would drop before aesthetic losses would be first noticed.

There is a strongly positive attitude towards the conservation of wetlands among Jandakot residents. Definitions of conservation vary among residents. Both water level and water quality issues were of concern.

There is a need to understand more of the relationship between community aesthetics, knowledge of wetlands ecology and conservation values.

Residents expect conservation-oriented criteria to:

(a) conserve wetlands, flora and fauna

(b) prevent development too close to the lakes

(c) set stringent criteria for pollution control

Values relating to personal well being include the economic value of living near a "good view". The wetlands also have a considerable recreation value. This value depends on the recent biological and social history of the lakes, the capacity of the environment to accommodate activities and the socio-psychological needs met.

Our community study indicated that there was strong support for passive recreation around the lakes and a majority indicated that horse-riding was an acceptable pastime. There is a potential for conflict between passive recreators and horse-riders. However, there is not adequate information to gauge the socio-psychological needs which are being met by the wetlands.

Problems associated with the management of midges are summarised as are possible future quality of life issues connected with rising water-tables and wetland pollution deriving from home garden fertilising in emerging urban areas.

Cultural factors as influences on responses to the survey by differing interest groups in the Jandakot region have been examined, but the values and attitudes of the groups are similar. The importance of including neighbourhood concerns is emphasised.

General social criteria are offered for lakes in the study area, based on the above findings. It is concluded that gradual trends away from past water levels may be tolerated in some lakes and that pollution standards should be high. Special consideration may have to be given to deriving standards for the ephemeral wetlands.

The report concludes with a description of a process for setting criteria which takes account of the diversity of values within the community and the uncertainty involved with decision making. Public involvement programs are suggested for deriving, initially, the relevant dimensions of the criteria and, at a later stage, their critical values.

1. INTRODUCTION

The objective of this document is to suggest criteria, and procedures for revising those criteria from time to time, that will help the Water Authority decide whether the impacts on wetlands of pumping by both the public and the private sectors are socially acceptable.

At the first meeting of the study group, it was agreed to evaluate those impacts, measured in terms of water levels and contaminant concentrations. However, social interests are related to these measures only indirectly and often in complex ways. We must point out at the very beginning that the research that would answer direct questions about water levels is very site-specific in its outcomes and mostly has not been done. We can offer some guidance based on our research into related matters and the literature, but we will largely be establishing a procedural framework within which numerical criteria can be set.

In Section 2, we consider the definition of 'criterion', and compare our approach to others that have been used in the local context. In Section 3, we show how criteria can be derived in a general fashion from basic categories of human needs, with special attention to the fundamental differences between 'social' criteria and 'ecological' criteria. In Section 4, we review the findings of a survey in the Jandakot area that touched on some relevant human needs. In Section 5, we apply the information to specific lakes in the Jandakot area, in as much detail as the available data will permit. Section 6 covers procedures for handling uncertainty, change and diversity of opinion.

2. CRITERIA AND THEIR INTERACTIONS

2.1 What Is a Criterion?

The Oxford English Dictionary (OED) gives two slightly differing definitions of 'criterion'.

(i) A test ... by which anything is judged or estimated.

(ii) A distinguishing mark ... attaching to a thing, by which it can be judged or estimated.

Using both definitions together may lead to confusion in practice, so we shall explain our usage.

In this report, we are concerned with the procedure and reasoning by which water levels (and, to a lesser degree, the concentrations of pollutants) are to be declared satisfactory or unsatisfactory in social terms, because these dominate community attitudes. The task is to suggest *values* of those water levels (or concentrations) that are *socially acceptable.*

Suppose it is said that (at some place and time) 'A water level greater than 12m AHD is socially unacceptable because access by casual walkers is impossible'. In saying this, a numerical value of the water level has been singled out and a reason given. The *reason* serves to define a *test* by which the activities of the Water Authority may be judged. If reason R explains why water levels greater than X metres are unacceptable, then the question Q: 'If the level is Z, is R true?' is a test for the acceptability of Z.

Using the alternative dictionary definitions, the criterion of acceptability might be either the level X itself (the 'distinguishing mark'), or the question Q (the 'test'). We will take the second alternative, and refer to the question as a *criterion,* and to X as a *critical value* of the *criterion variable,* water level.

This usage is distinct from the one in which some other variable, such as ecosystem diversity, that may be causally affected by water level, is called a 'criterion'. According to our usage, a 'criterion' is a test such as: 'If water level falls below 12m AHD, will species Q be able to breed?' OR '... will diversity be above 0.6?' Either 'Breeding by species Q', or 'Diversity above 0.6', might be treated as a criterion of a healthy lake in the OED's sense of 'a distinguishing mark'. However, such variables might better be called not criteria but *objectives,* since they are usually things which are taken as good in themselves. If this were done it would remove some potential for confusion with the criterion variables that are the Water Authority's more direct concern.

We compare the approach we have taken above with that in the 'Draft Guidelines for Wetland Conservation in the Perth Metropolitan Area' (Environmental Protection Authority 1986). In this document, two aggregated variables, 'Natural Attributes' and 'Human-Use Attributes', are used to classify wetlands into five categories with different management priorities. In our sense, these variables are criterion variables, but the criterion is one of category membership, not directly a criterion of social acceptability.

There are number of reasons why the criterion variables in the Draft Guidelines are poor proxies for social acceptability criterion variables:

(i) the component variables have in some cases little evident connection to social welfare or acceptability,

(ii) there is double counting in using the judgements of previous reports as components,

(iii) the aggregate variables are arbitrarily weighted sums of their components,

(iv) the aggregate variables have a multi-factorial structure; for example both passive and active recreation, which often conflict, are added as though they can both contribute positively to the score.

It is instructive to look at the use of criteria by LeProvost, Semeniuk & Chalmer (Western Australian Water Resources Council 1987) (LSC hereafter). Drawing on previous work, these authors suggest sixteen 'criteria' for wetlands. These are phrased as questions, and thus are in our terms also criteria, but they are, like the criteria in the Draft Guidelines, criteria for categorisation of wetlands, not for the acceptability of water levels. To fulfil this function, they would have to be rephrased as what we have termed 'objectives.' For example, their number 14 would correspond to an objective called 'Active water-based recreation'.

This is, in the first place, a grammatical difference rather than a criticism, as LSC had a different objective for their study. They sensibly - in our view - decline to use weighted sums of criteria, preferring to use a finding of ecological significance on a number of scales as grounds for arguing for the overall significance of a wetland. We note also that they claimed no expertise on the five criteria of a social kind that they mentioned. This is especially appropriate as expert testimony on these points is only part of the story, as we shall describe below.

However, the LSC methodology tends to lead to a rating or ranking of wetlands, with the further expectation of the sacrifice of lowly rated ones, even if in some sense they have a net positive value. It is highly important to observe that since the content of our study has been defined as the setting of what we have called 'critical values', without reference to what is practicable, we have effectively been asked to avoid considering the most important potential source of conflict in the system.

2.2 Interactions of Criteria

In Figure 1 we have indicated how we think of a series of criteria as defining a trajectory for the levels of a lake during a year. The trajectory itself is drawn as a fuzzy line as a reminder of the existence of uncertainty due to weather and the limits of aquifer modelling. What are visible on the figure as definite black markers are what we have called critical levels: the reasons for placing them on the diagram are to be found in the criteria. From the diagram one cannot expect to evaluate the performance of the trajectory with respect to such criteria as: feasibility of the proposed regime, simplicity of administration or clarity of purpose. However it is possible to a limited extent to discuss conflict between criteria.

Criteria may be different at different times of the year. The altered social criteria may then present management problems and perhaps be incompatible.

The simplest criteria depend only on the state of individual wetlands. In such cases, conflict might look like Figure 2. In the next section we distinguish the cases of conflicts that arise from inconsistencies among one person's values and cases of interpersonal conflict. It is important to know the source of such conflicts because in the latter case the critical level (or, equivalently, the criterion that takes precedence) can only be known as the result of a negotiation.

If there is a possibility that, for a substantial number of people, the value being satisfied by one criterion in one wetland is substitutable for that in another, then there is the possibility of making tradeoffs. It is difficult to show these in diagrams but Figure 3 allows us to draw a simple example.

3. SOCIAL ACCEPTABILITY

A water level may be said to be socially acceptable if a large proportion of affected people agree that it passes the criteria they consider important. This can happen if they are all using the same criterion: more often it is good social policy to try to pass a diversity of criteria. If neither approach works, there is conflict. If there is conflict, any acceptability possible is the outcome of a negotiation, rather than of a pre-specified criterion. This is an important difference between what might be called 'social' criteria and 'ecological' criteria. Ecosystems do not change their opinions. As a consequence, 'ecological' criteria are usually presented as non-negotiable 'needs' of an ecosystem, as contrasted with the fickle and materialistic 'wishes' of society.

We would like to point out that this is misleading. It is possible to some extent to make an imaginative leap to what the inhabitants of natural ecosystems would demand if they could be asked their opinions. Nonetheless all criteria for ecosystem management are the result of humans attempting to satisfy their own wishes and needs, according to their understanding of their situation. Among these wishes and needs are wishes (and needs) for various grades of preservation and conservation of natural ecosystems. It is sometimes felt politically sensible to minimise these facts. For instance, to speak of the requirements of the health of an ecosystem tends to disguise a human-centred assertion of the higher value of particular ecosystem states under an apparently less value-laden assertion about ecosystem function.

Our position is that all criteria are human criteria, though some are more altruistic than others. It is on this basis that we have to build to develop criteria of social acceptability. From this point of view, the designers of ecological criteria are an interest group with a surprising amount of influence considering their numbers, influence that arises partly from the general conservation attitudes in the community.

Figure 4 diagrams a simple social-psychological model of how human criteria arise. The model states that criteria are derived from legitimate expectations, which in turn are determined by values, which are expressed by attitudes and behaviours. Values may be defined as basic psychological categories of preferences about how the self or the world should be. Values provide humans with standards to guide general conduct and provide a motivation to achieve general goals (Rokeach, 1973). Attitudes are affective (or emotional) reactions to specific objects or behaviours (Fishbein and Ajzen, 1975).

Values lead to specific attitudes and behaviour. Individuals prefer there to be consistency at each level and across levels: for example they avoid having attitudes that lead to incompatible behaviours. When inconsistencies occur, the individual is motivated to change an inconsistent component so that a clear self image on particular issues may emerge (Kantola Syme and Campbell, 1984).

In our present context, a value would be the belief that wetlands should be conserved. An attitude would be a feeling about the level of clearing permissible around Thomsons Lake. Finally, recreational activities undertaken on a lake such as bird watching would be a typical example of behaviour. An example of inconsistency would be a situation where an individual supports the preservation of ducks, but also has a very negative attitude towards midges, and lake smells. The first attitude reflects a conservation value and the second one relates to personal well-being. This inconsistency will be resolved by the individual deciding which is the most important value and, for example, rationalising the inconsistency by deciding that one should put up with the inconveniences of wetlands for the good of the overall environment.

As this discussion suggests, although it would be convenient to establish general and stable standards for management of water bodies this is impossible given the idiosyncratic historical and social context of the development of community perceptions. As well as variability of criteria from place to place - possibly even from lake to lake, let alone from nation to nation - there may be variability over time as the value structure of the community changes. Socially acceptable criteria for wetlands management in the 1940s for example would have been different from those appropriate today. Brande (1980) shows how attitudes towards wetlands have not merely altered in strength in recent times but in some cases completely reversed.

To take account of these sources of variability, after suggesting appropriate social bases for deriving wetland criteria, we offer mechanisms for maintaining consistency between criteria in environmental, social and individual contexts. We also suggest some evaluative methods for the review of criteria as it is deemed necessary.

4. EVIDENCE BEARING ON JANDAKOT

In the survey that we carried out in the Jandakot area (Macpherson and Syme, 1988), we were concerned mainly with public perception of the fairness of different approaches to water allocation. However in investigating the social context for these perceptions, we collected information about both general concern for wetlands and the acceptability of different types of human activity in them. Some of this information was collected in the form of quantitative indices, but part of it consisted of free-form responses to questions about environmental concerns. Collation of these free-form responses suggests three main dimensions of concern that are close to those listed in the LSC study, though more detailed in content:

TABLE 1
Values and Related Issues

Value	*Related Issues that Generate Attitudes*
Aesthetic	clearing around lakes environment for passive recreation mud-flats (appearance and smell)
Altruistic/conservation	wildlife preservation vegetation preservation natural appearance of wetlands and bush
Personal well-being	property values recreation midges threat of flooding urbanisation

We anticipated that these values might be cross-cut by cultural differences among local groups, and by perceptual distinctions made by people between their immediate neighbourhood and regions of larger size.

These values are not so much categories as independent dimensions. A concern may rate on more than one dimension. Mudflats and associated smells are a personal inconvenience as well as unpleasing in appearance. Property values are a material concern depending partly on aesthetics. More importantly, in the present context, we have the impression that since the public has a fairly low level of information on aquifer and wetland function, it tends to interprèt 'conservation' issues in aesthetic terms. This may imply a place for public education campaigns: on the other hand it has been argued (Olwig, 1984) that the methodologies used by landscape ecologists are responsible for the opposition observed between 'ecological' and 'aesthetic' approaches to landscape.

In the rest of this section we use international and local literature and community survey results from Jandakot to establish the social background against which community expectations or standards are derived before nominating social criteria for wetland management as a whole and for particular lakes. We discuss each of the social components in terms of generalised human values and also in terms of specific attitudes and behaviours recorded among the Jandakot community.

4.1 Aesthetic Considerations

The landscape aspects of the management of wetlands are the preeminent ones from the public viewpoint because, as we indicated above, they may absorb a fair amount of what the community understands by 'conservation'. The local lakes provide an important water based natural focus within the Perth metropolitan area.

Until now most assessment of the value of such landscapes to the community have followed 'expert-driven' ecological or formal aesthetic models which have involved expert planner assessment of particular vistas (Daniel and Vining, 1983; Western Australian Water Resources Council, 1987). There are however a number of increasingly accepted ways of measuring community preferences and these have revealed a number of consistent findings.

4.1.1 *The Attractiveness of Water*

Of most interest in this context are findings that people consistently prefer natural settings in the urban environment (Kaplan, 1983). Studies also consistently demonstrate a very high preference for scenes in which water bodies are present as compared with other landscapes (Ulrich, 1983). There is considerable evidence that water is the dominant visual landscape property and nearly always enhances the overall valuation. Some authors have even suggested that such a preference has an evolutionary basis for man (see Ulrich [1983] for review). In the urban planning context Alexander et al (1977) state "We come from water; our bodies are largely water; and water plays a fundamental role in our psychology." On this basis these authors suggest that every neighbourhood should be provided with some still water such as a pond or a pool.

The relationship between the amount of water and appreciation of a landscape will obviously vary from scene to scene but it is clear from the international literature on the values associated with water that largish bodies of open water are likely to be very much appreciated as significant aesthetic assets for the environment.

At the value level this has two consequences. Firstly, management practices which result in noticeable diminution of currently perceived levels of open water in lakes will be opposed by the community (see Wohlwill and Harris [1980] for a discussion on acceptable levels of change in landscape). The second major consequence of these findings is that distinct aesthetic advantages could be gained by consolidation of drainage into "artificial" expanses of water rather than the employment of individual sumps at particular points.

4.1.2 *The Value of a View*

Crossing to an attitude dependent on a closely related materialist value, there is both international and local evidence that considerable and measurable economic value can be placed on views of rivers and lakes. McLeod (1984) has shown in the Perth context that just over a quarter of the values of houses close to the river can be explained by Swan river views.

More recently, Blomquist (1988) has used contingent valuation or willingness-to-pay questionnaires to demonstrate that householders are prepared to pay substantial amounts to obtain a view of Lake Michigan whereas regional residents have also provided monetary values for the protection of the Lake Michigan shore from being built upon. These subjective valuations were validated by more traditional market analyses.

4.1.3 *Aesthetic Opinions from Jandakot*

The issue of water views was addressed peripherally in the recent Jandakot community survey when residents were asked whether they thought having a lake view affected the values of properties in the area. Just over half (54%) thought that values would increase, nearly one-third thought there would be no change while a mere 8% thought there would be a lessening in value. When the same question was asked in relation to wetlands however a markedly different pattern of response emerged. On this occasion only 15% thought that the value of their property would be increased whilst 62% thought there would be no change and 20% of people considered their property value dropped. Apparently the thought of open areas of water is more appealing than that of wetlands, at least in property value terms. These results tend to confirm the high aesthetic appreciation of open bodies of water.

TABLE 2

Attitudes Towards Clearing Around Wetlands

Attitudes	*Respondents agreeing*
Clearing should not be allowed	37%
Some of lake can be cleared but not all	81%
More clearing will be acceptable	16%
There is too much clearing going on	71%
No more than half lake shore should be cleared	68%
Clearing to water's edge achieves best appearance	22%
Clearing should be kept to a minimum needed for home owners and tourists to see water	79%
Amount of clearing should be determined by wildlife needs	89%
No strong views on clearing	29%

The Jandakot survey asked residents about their perceptions of current levels of clearing around both wetlands and lakes. There was divided opinion about whether there was already too much housing (18%) or whether there was room for more (18%). About half the sample thought that the current level of urban development was "about right".

We also asked people about their views on clearing around wetlands and lakes. Responses are shown in Table 2. As can be seen there was concern among a majority that there was too much clearing going on already. People gave strongest support to clearing programs which both gave a view and protected the needs of wildlife. Again this demonstrates the importance attached by the community to the aesthetic value of open areas of water.

4.1.4 *Research Needs in Aesthetics*

The questions of how water is perceived in the landscape by the local community could and perhaps should be more adequately measured. In addition, while we have emphasised the important role of water in governing aesthetic preference there are several other psychological dimensions such as mystery and threat (e.g. see Ulrich, 1983) which need to be quantified if the lake landscapes are to be adequately assessed.

Studies could be conducted among local community members using slides of current and possible landscape futures for each lake. There are a number of psychologically based techniques which could be used to demonstrate the type and consistency of preferences for landscape. Perhaps the most appropriate method would be the psychophysical technique (e.g. Daniel and Schroeder, 1979). This technique would involve presentation of a number of slides of the lakes from a variety of angles during differing seasons. As necessary water levels and bush characteristics could be artificially created to present alternative futures for these environments.

A scenic beauty estimation can be offered by the respondent for each slide. The slides can then be characterised by the percentage water cover and the degree of clearing and a model of the relative importance of each for assessing scenic beauty calculated. The effect of clearing and drawdown of water for the lakes on perceived beauty could then be inferred. Such an exercise would create quite precise details of the social acceptability of variations in water level and clearing.

The other research suggested by the Jandakot community survey is that there is a need for a more precise understanding of the community differences in understanding, perceptions and appreciation of the terms 'lakes' and 'wetlands'. Perhaps this could be achieved by carrying out the landscape work suggested for the more major lakes for the more ephemeral wetlands as well, and comparing the results.

4.1.5 *Community Expectations for Aesthetic Objectives*

There is both direct and indirect evidence that the community would expect planning to:

(a) preserve landscape aesthetics associated with open bodies of water

(b) clear bush in such a way as to maintain a view of the lake but not do this in a way which would disadvantage wildlife

(c) maintain high water levels (or levels little below recent historic levels) unless there is some clear reason to the contrary

(d) use any opportunities provided by drainage to create open bodies of water.

These objectives are stated largely in terms of lake areas. Without further information, it is hard to make any more than relative statements about the likely responses to changes in water level. However we can say that those lakes where the bathometry indicates that a small change in water level would result in a large change in area can be regarded as being aesthetically sensitive. This point is illustrated in Figure 3. In Section 5 we make this point more specifically for those wetlands where the data permit.

If we wish to go beyond this level of discrimination, community based landscape assessment techniques are available to create quite precise limits to community acceptance for the effects of changes in the water-table. It also seems important to improve our understanding of peoples understanding and aesthetic appreciation of lakes as opposed to wetlands.

4.2 Conservation of Wetlands

There was a strong expression of conservationist values among those who were surveyed in Jandakot. Ninety seven percent of those surveyed stated that they liked to consider themselves as conservationists.

4.2.1 *Attitudes Towards Lakes, Wetlands and Natural Bush*

Specific attitudes towards wetlands were consistent with this expression. The preservation and maintenance of wetlands was a major issue for the vast majority of people in the survey. Wetlands were seen as being important by nearly 90% of respondents and 96% of respondents considered their maintenance in good condition as important. In addition 86% of our respondents agreed to varying degrees that if they were to participate in planning one of their aims would be to help protect the wetlands generally and 96% said that their aims would be to protect groundwater quality. Finally, about 70% of respondents felt that there should be no urban development near wetlands. Our reading of regional values is that they are likely to be the same.

These attitudes reflect a high incidence of concern about both maintenance of the wetlands system generally and water quality issues in particular. These opinions seem to be based substantially on the respondents' general conservation values.

(About one-third of respondents did not believe that planners would be able to conserve the wetlands or prevent groundwater pollution. This indicates the importance of demonstrating to a sizeable minority that conservation criteria can be achieved.)

While these values and attitudes may be regarded as important motivators of expectations it is important to note that one person's conserved wetland may be another's ornamental pond. A further issue is that in aesthetic and behaviourial terms people, at least in river settings, appear to be fairly tolerant of water pollution (Moser, 1984). Gradual changes may not be noticed for some time: indicators of pollution may not be recognised as such. The survey did not ask respondents what distinguished a healthy wetland and, as we have indicated above, the degree of discrimination between good aesthetics and good conservation may depend on the knowledge and experience of the respondent.

Nevertheless there is considerable knowledge in relation to happenings in wetlands and the survey elicited 400 specific concerns about the various lakes. These responses are summarised in Appendix 1 of this report. The comments largely support the general attitudes above both in content and frequency and provide many specific area examples of problems. An area analysis showed, perhaps not surprisingly, that more comments were elicited from residents near to lakes than those further away (this was not true of other attitudes). This latter finding does however point to the need for consideration of neighbourhood expectations in developing social criteria. This is discussed below in more detail.

4.2.2 *Research Needs in Conservation*

There is a need for further explication of the relationship between community knowledge, aesthetic preferences and their definition of conservation in regard to criteria in this area.

4.2.3 *Community Expectations and Conservation Objectives*

(a) It is clear from both the expressed values and specific concerns expressed that there is strong support for conservation of the lakes and their associated flora and fauna.

(b) There is opposition to urban development 'too close' to wetlands and this will have to be considered when devising land use criteria.

(c) There is a clear indication that many in the community will need to be satisfied that there are stringent criteria in relation to pollution control.

(d) It is not clear precisely what the community consider good management in relation to conservation criteria.

4.3 Personal Well-Being

Under this heading we have grouped those values that might loosely be termed 'selfish', as distinct from altruistic regard for the interests of the natural world, or non-self-regarding pleasure in its beauty. 'Selfish' interests, of course, include primary human needs like shelter, as well as matters of taste, and anti-social or anti-environmental inclinations.

4.3.1 *Economic Effects*

We have already discussed (Section 4.1.2) the investment aspect of having a lake view from one's house. From the responses to our survey it was evident that having a lake view gave aesthetic value and was also expected to give a monetary reward in terms of housing values. If current (and long-established) taste is for large bodies of water without too much surrounding vegetation and without expanses of mud, it follows that control of water levels could have a significant economic impact on individual householders, one that might even be more important than that of licensing commercial water use. If the Water Authority assumes responsibility for a more precise degree of control than in the past, it should expect to have higher public demands made on it and to be the recipient of closer scrutiny.

4.3.2 *Wetlands, Lakes and Recreation*

There are three distinct levels at which recreational needs interact with the creation of standards in wetlands. The first level is the ecological and development history of the particular lake (Wollmuth, Schomaker and Merriam, 1985). Secondly there is the level of current activities, their appropriateness for the area, and the capacity of the environment to accommodate them (Catton, 1983, O'Brien, 1988). Finally the socio-psychological needs fulfilled by these activities and their inter-substitutability need to be assessed (O'Leary, Field and Schreuder, 1974; Wollmuth et al, 1985; Knopf, 1983).

Factors at all these levels will govern the community's expectations in regard to recreational criteria. In Jandakot, there are clear differences in the recent biological and social history of the various lakes which will affect current recreational activities and expectations for future recreational development. These will be discussed for the main individual water bodies in Section 5, but two extreme examples would be Bibra Lake and Thomsons Lake. The first environment has already been substantially cleared, is situated besides a major fun park and is generally urban in character. It is characterised by a relatively large expanse of open water. In contrast, Thomsons Lake has had the status of a reserve, is not cleared and while having a large area provides a varied landscape (including introduced plants such as Typha) with both water and vegetation features.

This contrast creates some flexibility for the planner planning with social criteria in mind. Clearly the community's strong conservation values may find expression in conservation based criteria for Thomsons Lake whilst its more active recreational values may find expression around Bibra Lake. We are trying to emphasise that the diversity in recent history and ecological condition of the various lakes provides an opportunity for planners to maximise the diversity of social values that the chain of wetlands meet, which in turn increases the social acceptability of a plan.

These values will, of course, only be met if we understand how these are expressed currently and what the carrying capacity of the lakes may be if the preferred recreations are to be pursued on an environmentally and socially defensible basis. We are not aware of any study clearly defining the current recreational activities for the Beeliar Lakes although there have been some limited studies of recreational activities for individual lakes (e.g. Yangebup). As a consequence definitions of carrying capacities and conflict between alternative current users of the system are not available.

Nevertheless our survey gave some generalised information of current recreational uses of natural bushland and wetlands in the sub-regional area and what residents regarded as acceptable recreation for wetland and bush environments. Respondents were prompted with a list of recreational activities, but asked to add others if they wished: few activities were added. Responses to these questions are shown in Table 3.

TABLE 3
Acceptable Activities in Wetlands

COLUMN A. Question: Which of the following uses of the wetlands and natural bush areas are acceptable to you?

COLUMN B. Question: Which activities do you undertake in wetlands or natural bush?

Activity Type in Wetland	*(A)* *Acceptable to Respondent*	*(B)* *Undertaken by Respondent*
Bird-watching	97%	30%
Picnicking	83%	30%
Bushwalking	96%	59%
Horse-riding	66%	22%
Canoeing	62%	4%
Educational and research	96%	8%
Residential development	27%	3%
Industrial development	7%	0%
None at all	11%	

The most acceptable recreations were nature orientated (bird watching, bushwalking). This ranking of acceptability is mirrored in the activities actually undertaken by the respondents. The Murdoch University survey of Yangebup residents also indicated a strong support for passive recreational activities, which in their classification included bicycling (Murdoch University, 1988).

The one contentious activity from the regional survey was horseriding, which had the approval of two-thirds of the respondents as a desirable activity and the active participation of one-fifth of respondents. This activity was nominated as the basis of particular concern about environmental impact of a substantial number of those answering the questionnaire and making submissions to the Jandakot Study (Macpherson and Syme, 1988).

Horseriding may be an area where the dominant values of the regional community in regard to the wetlands conflict most with those of the horseriding local residents who see the Jandakot Lakes as an important resource for active recreation. There is a need for research to find out what characteristics of areas make them desirable for horseriding and what non-conservation areas can substitute in these respects. It may be desirable, as well as directing horseriding to more highly managed areas, to consider using artificial areas of water for creation of enjoyable water based environments for horseriders.

Given the paucity of research on the motivation for specific recreation activities, we know little about what values are being satisfied by recreational in the region. In a river environment, and for the one activity of rafting, Wollmuth et al (1985) have shown that at least five needs: self fulfilment, nature and learning, change from daily routine, solitude/introspection and affiliation were all relevant variables.

The degree to which these needs were met in the case of the raft users was not a simple function of the landscape or degree of development around the varying rivers studied but seemed to be a depend in a complicated way on variables such as previous personal experience. On the basis of their study these authors concluded that physical classification of water environments by landscape experts may not necessarily reflect the community's perception of the recreational significance of the environment. Consequently adequate community consultation would be required to create adequate recreational criteria for particular areas.

The Wollmuth et al (1985) study incorporated only one activity but studies of a wide range of activities in natural settings have shown systematic differences in the psychological benefits of differing activities which may not be directly related to the physical landscape (O'Leary et al, 1974; Knopf, 1983).

4.3.2.1 *Research Needs and Recreational Criteria*

Previous sections have attempted to make the link between data and likely local objectives for wetlands, if not the critical values of water level and water quality. Recreation, although an important issue, involves more uncertainty than some of the other issues, and we must restrict ourselves to more general remarks about procedures that will have to be gone through before socially acceptable criteria can be derived.

Driver and Brown (1983) provide a succinct set of required tasks for recreation policy makers and planners. These are:

(1) To determine how many scarce public resources will be allocated to outdoor-recreation programs,

(2) To provide appropriate high-quality recreation opportunities once basic allocations have been made,

(3) To protect the biophysical and cultural historical recreation resources from unacceptable change or damage,

(4) To reasonably protect the users from harm,

(5) To evaluate the effectiveness of the results of the above actions.

This list summarises the important steps which should be undertaken by recreation planners for the Beeliar park. To this we would add that there is a need for a formal social psychological study at the first stage in this procedure to establish the social importance of recreational values and attitudes which are met by current recreational activities in Beeliar. The study should also address the issue of substitutability and conflict even before the allocations in Driver and Brown's first step (above) are made. This information will provide planners with the social expectations which can provide the basis upon which recreational criteria can be set.

As the literature reviewed briefly above indicates, recreational planning in the natural environment is more than just the outcome of physical or biological landscape classification.

4.3.3 *Midges*

Appendix 1 shows, from the Jandakot community survey data, that there was a some degree of concern about the inconvenience of midges associated with wetlands. There was also concern about the use of sprays to control midges. Concern was mostly evident around Lake Forrestdale although considerable levels of inconvenience were reported in the Murdoch University survey of Yangebup (Murdoch University, 1988).

Concern about midges is also evident in the media and it seems to be an ongoing issue on the agenda for wetlands management in the area. The City of Cockburn hopes to have pre-empted the problem by creating a buffer zone around the lakes of one kilometre thus avoiding the nuisance of public inconvenience and complaints whilst promoting conservation of the wetlands. The Cockburn City policy cleverly removes the possible conflict in aesthetic and recreational values for prospective residents by removing a multiple-use option (Cockburn City, 1987).

In other areas the midge problem may be controlled by encouraging higher water levels to enhance aesthetic factors while reducing midge numbers. Thus the strong conservation values evident in the community would not be reflected in the management of some lakes.

4.3.4 *Rising Water-Tables*

Although most environmental concern has concentrated on lowering of water-tables, increased urbanisation in the Jandakot area has been correlated with rising water-tables and lake levels. A question in the community survey asked how people thought they would be "affected by a rise in the water table." Nearly a quarter of respondents said they would be concerned about flooding in the area. This concern is likely to be exacerbated as relatively cheap land in the area invites further urban development.

It seems important that the fears of a substantial minority of people that significant flooding may occur around wetlands needs to be seriously considered. As Ulrich (1983) points out, fears such as these are incorporated in people's attitudes towards their local environment as a threat or tension dimension. If this dimension has a consistently high loading in one's neighbourhood it can have a substantial effect in lowering one's overall quality of life.

4.3.4.1 *Research Needs on Criteria for Maximum Water-Table Levels*

There is a need to consult with the public to establish their attitudes towards the risk of flooding in the Jandakot area and to ascertain their expectations as to acceptable risk criteria.

4.3.5 *Urbanisation and Lakes*

Future urbanisation near lakes may cause pollution as well as rising water-tables. Among other things home gardening fertilisers may pose some threat to both conservation and aesthetic values in wetlands.

The Perth Domestic Water Use Study (Metropolitan Water Authority, 1985) clearly demonstrated the extremely high value that people place on their home gardening environment. Such positive attitudes have also been observed in many other urban situations (Kaplan, 1983).

In Perth, care for gardens is expressed by the willingness of householders to sink a private bore and to apply fertiliser on a regular basis to their lawns and gardens. While the extent of home fertiliser use and its possible effect on lake water quality has not been quantified, current gardening practices or behaviours may need to be monitored to ensure environmental protection.

If necessary, criteria relating to home use of fertilisers and chemicals may have to be introduced in a socially acceptable manner. This will be difficult if lakeside communities feel as though they are not being treated in a fair way in comparison with other members of the community who have unfettered gardening practices.

4.3.5.1 *Impact of Urban Development on Water Quality Criteria*

The possible effects of home gardening activities on local lake water quality need to be estimated. Consultative procedures for balancing the criteria expressed in the householder's preference for an aesthetically pleasing home garden and in the obvious community desire for clean lakes and groundwater may need to be set up. These procedures would have to ensure that there was a high level of knowledge in the wider community of the trade-offs between green lawns and healthy lakes.

If feasible we recommend that any restrictions on use of fertilisers or access to private home bores be introduced as a condition of sale rather than imposed later. It is easier for the public to accept a once-and-for-all decision in relation to behaviourial change rather than be weaned off existing practices which may have grown to a central importance in a person's quality of life (e.g. see Syme and Seligman, 1987). This is the approach recently adopted by the City of Cockburn in relation to the location of housing near lakes (Cockburn City, 1987), one which is likely to be successful. If people believe or are adequately persuaded that they cannot expect to live near lakes they are likely to accept such an environmental standard.

4.4 Cultural Diversity

Cultural diversity in the community's social history and its current demographic structure will affect the spread of interests found in the space of values that we have been considering. If this diversity occurs in the form of separate communities with strong identities, the task of finding acceptable criteria is made harder.

4.4.1 *Social Groups in the Jandakot Area*

In the past the Jandakot area has been characterised mainly by a rural orientation either as a private lifestyle or in market gardening. Since the late 1960s there has been a steady influx of urban dwellers in the areas surrounding the wetlands. An industrial area has also been developed near Lake Yangebup in the vicinity of the Wool Scourers which have been located near the water's edge for some decades. In recent times it does not seem that any identifiable community with special needs in regard to water has become established.

We analyzed our survey data to establish whether there were any particular differences in values or attitudes between the differing interest groups. We compared responses between market gardeners, special rural dwellers, urban dwellers in differing areas, and people working in local industry. A few differences did emerge. Some of these are discussed below. Nevertheless there seemed to be relatively uniform values between the differing groups and between group-conflict on desirable criteria seems at least at this stage to be minimal.

There are two groups not included in our survey who should also be considered in planning for the area. These are those residents of the metropolitan area who don't live in Jandakot but who think of the wetlands as a metropolitan regional resource. There are also the future residents who may buy blocks near the lakes. Where we think that there may be differences between these groups in future, appropriate procedures are discussed in Section 6.

4.4.2 *Effects of Culture-Based Expectations on Wetland Criteria*

There appear to be no major interest group differences in expectations for wetland criteria. However, we are concerned that there is no comprehensive regional study of metropolitan expectations in relation to wetlands criteria.

4.5 Effects of Spatial Scale

We have mentioned the contrast between treating the wetlands as a local (Jandakot) resource and as a regional resource in the development of socially based criteria. It is also important to recognize that many criteria will vary on a smaller or neighbourhood scale.

Many of the specific comments on lakes were obtained from this perspective. For example, concerns about abandoned cars in swamps at the end of one's own street were quite vehemently stated. The many international studies of participation in planning have shown a tendency for people to want to protect the quality of their local environment. This greater interest in involvement in neighbourhood rather than regional concerns was also evident in our study (Macpherson and Syme, 1988).

Sometimes called the NIMBY (Not In My Backyard Yard) syndrome (Marks and von Winterfeldt, 1984), this phenomenon is often decried by planners as self interest. It is important for establishing social criteria, though, because neighbourhoods in which there is a strong sense of unity and competence tend to have a better quality of life than others. Also, active neighbourhoods have individuals with extremely accurate knowledge of changes in their local environment. Such information can be of great value to planners.

4.5.1 *Neighbourhoods and Acceptability of Criteria*

Since the welfare of the region's residents is a function of that of each of the neighbourhoods it is important that social criteria are interpretable at the neighbourhood level. The specific application of this is that the value of various swamps, drainage areas and ephemeral wetlands may only be really appreciated from surveys at the neighbourhood level. The value may not be positive in every case (a danger from snakes may be feared, for example), but sampling opinion on too broad a scale, or establishing critical values of water level at too few of the mesh nodes of the groundwater model, may seriously underestimate the impact of water level changes on quality of life.

5. APPLICATIONS TO THE MAJOR WETLAND AREAS IN JANDAKOT

As we have emphasised in a number of places, the existing base of knowledge does not permit us to assert that particular numerical values of water levels at particular places and times will be found to be socially acceptable. Instead, a continuing program of routine public involvement will be required as part of administration of the area, in order to gather evidence of discontent and changing values and arrive at new criteria.

However it is possible to make some simple observations based on the following facts:

(a) The present state of affairs is a highly valued one.

(b) Gradual rather than sudden change is likely to be more acceptable.

(c) There is a natural classification of the wetlands we have been asked to consider into three groups - the Beeliar chain, Forrestdale and the ephemerals.

(d) There is a cline of decreasing urbanisation from north to south along the Beeliar chain.

(e) Increasing urbanisation has been associated with rising water levels, disturbance of natural communities, and the development of a 'garden city' from 'the bush'.

(f) People care about the conservation of their neighbourhood, but are generally willing to go elsewhere to satisfy specialised needs for recreation.

(g) Precise data is available on the area/water level relationship for the North, Forrestdale, Yangebup, Thomsons and Bibra lakes.

From these facts we can deduce that:

(a) The known baseline data on water levels, averaged over perhaps the past ten or fifteen years, represents a fairly acceptable set of critical values, and should be deviated from only slowly.

(b) At the North end of the Beeliar chain, acceptability will be heightened by maintaining high water levels that produce the valued aesthetic mode, provided this does not increase the risk of floods which will surely be the dominant criterion if applicable at all. If dynamic management involving occasional draw-downs for the preservation of water quality needs to be attempted, a program of public education will help. Of the lakes in this category for which the bathymetric data is available, North and Yangebup have been operating since about 1985 on a portion of their characteristic curves where area is not very sensitive to changes of the order of 1m in water level. However Bibra has been operating at a level where a 1m decrease would result in an areal change of order 50% and this should have a major aesthetic and hence social impact.

(c) At the South end of the Beeliar chain, there will be relatively high tolerance of 'unsightly' swamps and mudflats being maintained for ecological reasons. As urbanisation advances, this tolerance is likely to reduce, despite expressed values, unless a higher level of public awareness of ecological processes is induced, so that people have more reasons to value such attributes of areas. The only lake in this category for which the bathymetric data is available is Thomsons Lake, and over the past 5 years this has been operating on a region of its characteristic curve where it is not highly aesthetically sensitive to rises or falls of the order of 1m.

(d) The opinions of residents around Lake Forrestdale are even more diverse than in most neighbourhoods. It might be best to arrange water level criteria on the basis of the Forrestdale Lake Nature Reserve plan, and find out how local opinion wants this modified later. The bathymetric data for Forrestdale Lake confirms what our survey suggests: that this lake has been operating since the early 1970s on a portion of its characteristic curve corresponding to high aesthetic sensitivity to changes of +/- 1m.

(e) The ephemeral wetlands, though most likely to be impacted by pumping, have a lower aesthetic intensity than the major wetlands, and they also seem to be the least known biologically. As such, if they are valued it is likely to be on grounds of personal well-being, especially at the neighbourhood level. If there is any real scope for their accommodation in new plans, further investigation is needed to find out who values them and why and whether an annual stay of execution would satisfy these values at all.

(f) Pollution is not welcome anywhere: in the North of the area, the use of groundwater will be for gardens and so perhaps standards will be lower than in the South where humans, animals and some more sensitive plants will drink it.

(g) If recharging upslope areas of the mound with excess water from urbanised areas turns out to be acceptable under (f), it may be worth considering as a source of artificial areas of water where controversial active recreation can take place. A further argument for this may turn out to be found under (e), depending on what local values would otherwise be sacrificed for water supply.

(h) Aesthetic impacts are dominant in this list because we cannot interpret the bathymetric data to give perceived flood risks or effects on midges for changes of +/- 1m.

6. PROCEDURAL RECOMMENDATIONS

The process of coping with uncertainty and diversity through creating wetlands criteria is a social one. We observe from the hydrological records available from some wetlands, and from the published descriptions of the Perth Urban Water Balance Study, that there will inevitably be uncertainty about whether particular fluctuations in water level and (presumably) water quality are the result of Water Authority actions or not. In addition there will be uncertainty about predicting the effects of these actions. Finally, climatic variation will have the effect of disturbing plans that are made in too much detail.

We may also add the human uncertainties inherent in predicting demands for urban development, and difficulties in precisely measuring such preferences as aesthetic tastes and value trade-offs. It is evident that the system of criteria has to deal not only with the desirability of the expected outcome but with appropriate responses to unexpected outcomes. Decision makers should be able to count on a mandate to take some risks. As management of the resource is more tightly circumscribed, failure is bound to become more noticeable.

It is for these reasons that we have emphasised the need to understand and cater for diversity by retaining a range of criteria from groups with different expectations, attitudes and values, and preparing to manage conflict over their application. In catering for social diversity under uncertainty it may also be important to avoid decisions which have irreversible effects.

Our model of socially based wetland criteria suggests that they need to reflect the community's legitimate expectations which are in turn dependent on both group and individual values, attitudes and behaviours. We have already indicated that there is potential for conflict between the values and attitudes of community groups and even between the values of individuals at different times. We have also noted that expectations, like most culturally based phenomena, will change over time. This fact poses a challenge to environmental planners attempting to provide for appropriate levels of conservation.

To complicate matters, our review indicates that there is little existing specific data to assist the planner in evaluating proposed criteria. What is available instead in the literature is a good indication of the areas of concern which will need to be addressed.

How then should we progress in the setting of criteria which take community perceptions appropriately into account? We suggest that draft criteria should be set up by the planning team using the information from the various areas of biology, town planning, landscape assessment and so on which are currently available. The social assessment should then begin by checking specifically whether the dimensions we have suggested for summarising values are valid, and what criterion variables are appropriate measures. For example the chosen criteria might specify variability in lake level as well as absolute or mean levels. This first level of public comment could be gained from peak interest groups and local community interest groups.

If necessary the criterion variables of the draft criteria can be modified at this point. The second phase of social investigation (which may employ any or all of the methods discussed earlier in the review) should concentrate on that information which helps set the acceptable ranges of the criterion variables. This social investigation should incorporate public involvement from people with interests at neighbourhood, local and regional level. It should also identify the winners and losers at the regional level with respect to any particular criterion, and discussions of the trade-offs should be explicit (including alternative planning arrangements or land use compensation for any "loser" group).

Care should be taken to distribute sufficient information and encourage sufficient discussion to allow people to judge the impacts they will experience under each of the three value headings in this review. Finally, it is important that social factors relating to the running the wellfield under the criteria are understood and implementation strategies planned at the same time as the criteria are set. There is a need for criteria to be socially feasible - that is, capable of being explained and legitimated in practice - if they are to be successfully implemented (Hrezo, 1986).

It is not the function of this review to make specific suggestions about the exact organisation of the public consultation for this process but we suggest that the structure suggested by the Research Group on Groundwater Management (1988) would be an appropriate starting point. An educational or public awareness component of the program is likely to be important. Social feasibility of any complex pattern of criteria in time and space, and especially of criteria that offend against aesthetic attitudes, requires that the public are highly aware how the wetland ecosystems function.

Because there are so many competing expectations for use and conservation of the wetlands it must be emphasised that the final criteria need not be expected to resolve all conflict. Even though the criteria should be made as socially "robust" as possible, quite often the degrees of social freedom available to accommodate all views are considerably less than the number of views offered by the community. In the end the professional planner (including the water resource planner) has to make the decision, but at least with the above investigation it can be made with public knowledge of the costs and benefits involved.

Finally, we need to address the question of the different time scales at which human values and ecosystem properties change. This issue is one which concerns many environmentalists as they see the natural environment whittled away in successive trade-offs.

Currently, as a rule of thumb, in the Beeliar Lake chain the lakes are more urbanised in the north and more pristine to the south. At the moment, it is relatively easy to have some priority given to conservation. As urbanisation moves south, community values may change and pressure for more aesthetically oriented (in the sense we have been using) criteria may mount. It seems likely that this will happen faster than the natural time scale for the lakes themselves to fill naturally with sediment and organic matter. All we can suggest is that extensive and rigorous discussion of the social basis for criteria, done through the kind of public involvement that we have suggested, will tend to create the more complex set of public values that, from the point of view of conservation interests, is what is needed.

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APPENDIX 1

Concerns for Wetlands and Bush: Questionnaire Responses

Respondents were asked to name specific areas, if any, of the natural environment that were of concern to them. The responses to this section of the questionnaire are treated according to the particular geographical area referred to, the type of environment and the nature of the concern. A brief explanation of the coding used is followed by the data in tabular form.

(i) Area Codes

1. Thomsons Lake
2. Forrestdale Lake
3. Bibra Lake
4. Kogolup Lake
5. Yangebup Lake
6. North Lake
7. South Lakes
8. Other Minor Specific Lakes
9. The Spectacles and Other Specific Swamps
10. All/Specific Wetlands and Bush
11. Wetlands and/or Bush in Neighbourhood
12. Specific Bushland Areas
13. Other

The lakes specifically named in the areas had sufficient comments to warrant individual categories. A number of minor lakes were mentioned by name or geographic location, sufficiently often to deserve a category (Code 8) but not for individual categories. The same applies to Code 9 for swamps, where The Spectacles was named more often than others but not sufficiently often for its own separate category.

Responses were usually specific in their references to either lakes/wetlands alone, bush alone, or bush and wetlands together. While most respondents had comments on wetlands or bush individually, some referred to a combination of wetlands and bush, either specifically or overall, hence area 10.

Area code 11 is the category for those responses that concerned a particular area near the respondents' homes.

Where 'specific' appears in the title, the wetland/bush was named or indicated by geographic location. Where 'all' appears, the respondent was referring to the wetlands/bush as a whole or from an overall perspective. 'General' in the title is used where the respondent referred to wetland/bush in a generalised location as opposed to a specific location or as a whole.

(ii) **Comments Codes**

1. Remain and/or Protected in Natural State
2. Remain and/or Protected in Natural State for Wildlife and/or Flora
3. Remain in Natural State for People
4. Need for Midge/Insect Control
5. Concern for Present/Proposed Development in Area - Housing, Roads, Prison, Industry, etc.
6. Develop Picnic Area/Park for Recreational Use in Area
7. Concern for Dropping Water Level
8. Concern for Filling in of Wetlands
9. Concern for Neglect/Desecration/Destruction of Area
10. Concern for Pollution - Industrial and Introduced Weed, etc
11. Concern for Storm Water/Water being Pumped into Lake
12. Need to Balance Use by Wildlife and Humans
13. Other

QUESTIONNAIRE

Concern for Wetlands and Bush

	Area													
Comment	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*Total*
1	13	7	8	1	5	8	1	3	2	6	2	3	6	65
2	7	5	15	2	11	5	0	4	0	1	0	2	2	54
3	1	1	3	0	2	2	0	0	0	0	0	0	0	9
4	2	12	3	0	5	0	1	1	0	0	0	1	2	27
5	7	3	18	3	11	8	1	1	0	2	3	2	1	60
6	1	0	5	0	2	0	0	2	0	0	0	0	0	10
7	10	7	11	0	8	0	2	2	1	0	1	0	1	43
8	1	3	1	0	2	0	0	3	0	0	0	0	0	10
9	3	1	11	0	6	1	1	3	2	0	1	2	4	35
10	4	8	6	2	7	9	1	3	2	1	0	0	1	44
11	0	0	0	0	1	4	0	0	0	0	0	0	0	5
12	1	5	0	0	2	0	0	1	0	0	1	0	0	10
13	2	2	4	1	1	1	0	0	1	0	0	1	2	15
TOTAL	52	54	85	9	63	38	7	23	8	10	8	11	19	387

A more aggregated version of the data can be displayed by grouping the Area Codes into 4 more general categories, and similarly grouping the Comment Codes.

GENERAL AREA CODES:

Wetlands - Areas 1 - 9
Bushland - Area 12
Both Wetlands and Bush - Area 10
Local Environment - Area 11

GENERAL COMMENT CODES:

Conserve/Protect Environment - Comments 1,2,3,4
Control Development - Comments 5,6,12
Don't Pollute/Desecrate Environment - 7,8,9,10,11

	Conserve/Protect Environment	*Control Development*	*Don't Pollute/ Desecrate Environment*	*Total*
Wetlands	130	71	126	327
Bushland	6	2	2	10
Wetlands and Bush	7	2	1	10
Local Environment	2	4	2	8
TOTAL	145	79	131	355

NB: Area 13 (Other) & Comment 13 (Other) are not included.

REMARKS

162 respondents gave at least 1 area of wetland or bush of concern to them.

48 respondents mentioned a 2nd area.

19 respondents mentioned a 3rd area.

4 respondents mentioned a 4th area.

210 respondents gave at least 1 comment of concern for the environment. 48 of these do not appear in the above table as no specific area was given by these respondents. The comments, however, do not differ, as a group, from those tabled.

82 respondents gave a 2nd comment of concern.

36 respondents gave a 3rd comment of concern.

4 respondents gave a 4th comment of concern.

The above numbers of comments given do not add up to what is in the Table as some respondents gave one comment pertaining to more than one area or several comments pertaining to all of several areas.

Some detailed comments:

Five respondents asked why Thomsons Lake is drying up as it never did before. One of these reported that the salt water content has increased from 850 p.p.m to 1200 p.p.m in the last 12 months, possibly caused by either the dropping water level or the cement works allowing salt water to run into the area for years.

APPENDIX 2

Research Needs

For ease of reference this Appendix restates identified needs for information already mentioned in the main text.

A. AESTHETICS

The questions of how water is perceived in the landscape by the local community could and perhaps should be more adequately measured. In addition, while we have emphasised the important role of water in governing aesthetic preference there are several other psychological dimensions such as mystery and threat (e.g. see Ulrich, 1983) which need to be quantified if the lake landscapes are to be adequately assessed.

The other research need in aesthetics suggested by the Jandakot community survey is for a more precise understanding of the community differences in understanding, perceptions and appreciation of the terms 'lakes' and 'wetlands'. Perhaps this could be achieved by carrying out the landscape work suggested for the more major lakes for the more ephemeral wetlands as well, and comparing the results.

B. CONSERVATION

There is a need for further explication of the relationship between community knowledge, aesthetic preferences and their definition of conservation in regard to criteria in this area.

C. PERSONAL WELL-BEING

(i) Recreation

Driver and Brown (1983) provide a succinct set of required tasks for recreation policymakers and planners. These are:

(1) To determine how many scarce public resources will be allocated to outdoor-recreation programs,

(2) To provide appropriate high-quality recreation opportunities once basic allocations have been made,

(3) To protect the biophysical and cultural historical recreation resources from unacceptable change or damage,

(4) To reasonably protect the users from harm,

(5) To evaluate the effectiveness of the results of the above actions.

This list summarises the important steps which should be undertaken by recreation planners for the Beeliar park. To this we would add that there is a need for a formal social psychological study at the first stage in this procedure to establish the social importance of recreational values and attitudes which are met by current recreational activities in Beeliar. The study should also address the issue of substitutability of, and conflict between, activities even before the allocations in Driver and Brown's first step are made. This information will provide planners with the social expectations which can provide the base upon which recreational criteria can be set.

(ii) Flood Risks

There is a need to consult with the public to establish their attitudes towards the risk of flooding in the Jandakot area and to ascertain their expectations as to acceptable risk criteria.

D. REGIONAL EXPECTATIONS OF WETLANDS

There appear to be no major interest group differences in expectations for wetland criteria. However, we are concerned that there is no comprehensive regional study of metropolitan expectations in relation to wetlands criteria.

JANDAKOT GROUNDWATER SCHEME
STAGE 2

ENVIRONMENTAL CRITERIA
STUDY GROUP

VOLUME 2

Miscellaneous Aspects

PART E

Prepared by: Brian J O'Brien

September 1988

CONTENTS

1. PREAMBLE

The previous papers in this Volume 2 dealt with various specialist disciplines. This Part E deals with the issue of heritage, including aboriginal heritage, and with some incidental but anthropocentrically important issues such as smells and midges.

2. HERITAGE

In the absence of any Heritage Legislation in Western Australia, it is not immediately clear that the EPA will expect the Water Authority to include heritage issues in its Environmental Impact Assessment (EIA).

For the purposes of this report reference is made to the Australian Heritage Commission Act (1975) where

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

The aesthetic point of view is dealt with separately in this report.

From the historic point of view, Howroyd (1975) reported on the National Estate of the Town of Cockburn, much of which is relevant here.

He reported sixteen Aboriginal sites, all located more or less fortuitously in excavations for sand or in other quarries. However, Ms Vera Novak, Department of Aboriginal Sites, WA Museum, has advised that only three sites are listed on the Museum's register. These are all sites of archaeological significance that would not be affected by the proposed groundwater scheme. However, no systematic survey for archaeological sites bas been undertaken in the area and, therefore, there could be other presently unknown sites that could be affected.

Included in recommended future research, therefore, is approximately a two-day duration site visit to determine archaeological sites, if any, followed by an appropriate time for report writing.

With regard to ethnographic sites (i.e. those with spiritual significance for the Aboriginal people) though there are many in the area, the extensive changes wrought by European settlers over the past century, and documented elsewhere in this report, cannot he ignored. It is considered (Ken Colbung, pers.comm.) that these sites are now all converted (i.e. now without spiritual significance). The processes of public participation in the Environmental Impact Assessment will provide opportunity for further exploration of this matter.

The sites of historic importance, insofar as European settlement is concerned (including Smirk, Leaholme, Sloan and Wheatfield - also known as Greenkeeper - Cottages which are being conserved by the Town of Kwinana), should not be affected by the proposed groundwater scheme (A.S. O'Brien, pers.comm.). Relics of the Chinese Market Gardens that operated in the area around the turn of the century, have been absorbed by more recent agricultural activities, though there has been some private collection of artifacts.

To date the only trail to be developed in the area, as part of the Heritage Trails Network, follows existing roads and pathways and highlights historic sites related to the pioneer settlement of the area. It is called the Old Rockingham Heritage Trail and is a driving loop beginning in Rockingham. It is not considered relevant to this study as no construction work has been involved. The existing route has been signposted and a brochure on European settlement in the area is in the process of being prepared.

We have noted the reference in the draft brochure about the proposed Beeliar Regional Park that there is a Heritage Trail at Manning Lake, but that is outside the study area.

3. AIR POLLUTION AND SMELLS

For this study relating to Stage 2 of the Jandakot Groundwater Scheme, there is little to add relating to air pollution and smells.

The major potential environmental criterion in this regard is simply that every effort should be made to avoid noisome smells arising from dead and decaying algae and wildlife. An additional factor which could arise, should urban development go ahead, is the well-being of drains.

The only "wetland" smell that seems relevant is that from decaying blue-green algae. Conditions under which these can occur are a surfeit of nutrients and higher temperatures, so that they are most likely in summer as lake volumes diminish.

Browne-Cooper (pers.comm.) advises that occasional complaints are made, particularly about North Lake. One interesting aspect is that the smell is rather similar to that of an insecticide, such as DDT, so that complainants often are concerned about excessive sprayings whereas it is the dead algae that are responsible.

This is, of course, an example of the kind of environmental problem that can result from locating urban development too close to such lakes - the urban residents cultivate and fertilise their gardens so that the urban development, which causes increased water runoff, also causes increased nutrients in the lake that in turn lead to algal blooms whose decay leads to smells which in turn are complained about by the urban dweller. It is very relevant to our notions about creating naturally functioning urban lakes, and encouraging natural vegetation growth so as to filter out excess nutrients, while at the same time the health of such lakes is a measure of sensible environmental behaviour in the very same neighbourhood. Midges are a similar indicator.

If the bullet is bitten and urban development is permitted in wetlands such as Jandakot, then the bullet will be swallowed - and digested - if urban lakes are developed to act as neighbourhood watchdogs or monitors.

4. MIDGES

Clouds of non-biting midges (chironomids) can be a great nuisance to people living close to wetlands. Carried by the wind, they can be in plague-like proportions, particularly in summer, and since they are attracted by lights, they can be most unwelcome intruders to outdoor evening gatherings or open windows.

They appear to breed in greatest numbers in warmer, shallow water near the edges of deep wetlands or broadly across shallow wetlands with high nutrient content (J.A. Davis, S.A. Harrington and A.M. Pinder, "Investigations into More Effective Control of Nuisance Chironomids (Midges) in Metropolitan Wetlands, Perth, Western Australia", Murdoch University, 1988). For example, breakdown of algal blooms, themselves the result of excess nutrients, may have provided a large food source for larval midges inhabiting the sediments of North Lake and Forrestdale Lake in two events in the summer of 1987/1988.

In a sense, then, midges may be regarded as an environmental indicator that all is not well with a wetland, and that it is being overnourished, perhaps with nutrients from drains and run-off from fertilised suburban and rural areas.

Passive management to control midges may include planting of tall vegetation around wetlands to intercept the wind-blown midges. Davis et al (1988) suggest also that a well-developed band of fringing vegetation will tend to keep lake waters near the fringes cooler, an important factor because the growth of the pest species is favoured by warmer water temperatures. In addition, fringing rushes may act as natural filters to reduce nutrient levels, while bark from species such as Melaleuca increases the tannin content of a lake.

It is worth noting that both cooling and nutrient absorption will also tend to decrease the occurrence of algal blooms.

Active control of midges is predominantly by spraying pesticides, such as Abate (temephos), but there are indications of increasing local resistance to this pesticide in the long term.

To predict when there might be local midge problems, and to prevent them for a time, there might be a local monitoring of larvae densities in the bottom sediment, with spraying when the density rises above 2,000 larvae per square metre (Davis et al, 1988).

If one wants indicator organisms to show the condition of a wetland, one has to conclude that by the time there are plague swarms of midges, the wetland is environmentally quite sick.

5. AESTHETICS

The social factor of aesthetics is included in the legal definition of "environment" contained in the Environmental Protection Act (1986), and hence the Stage 2 development of the Jandakot Groundwater Scheme may be subject to analysis on the criterion of "aesthetics".

Here the aesthetics of pumps or water treatment plants or drains are not discussed. The aesthetics of major interest is quite simply the impression and potential enjoyment one has of various wetlands and lakes, and the aesthetic reactions to them drying up and exposing mud flats.

The response is highly personal and individual. It could be pseudo-quantified by some form of community questionnaire, but there is not much point to carrying that much beyond what has been achieved by Syme and Macpherson (Part D of this volume).

Instead, a preliminary report (J. Codner, 1988) on "aesthetics" was commissioned for this study, and could be incorporated in due course in an environmental impact assessment.

> The landscape in character is essentially shy, secret and hidden in gentle hollows and dense growth, [with] glimpses rather than views, showing floods of winter and early spring as a girl might flaunt a lacy petticoat, only to retreat in the harsh glare of summer.
>
> Clearing has exposed some of the views, delightful to European eyes, yet increasing the glare of reflection in summer and raising the water level in winter. The clearing of trees and scrub right into the lakes has taken away the natural progression of dry woodland to swamp leaving a sense of being unnatural, perhaps less noticeable in the greens of winter but more macabre in summer when the shrunken lakes appear unrelated to the few remaining tall trees.
>
> More positively, the introduced exotic plants offer dark and scented shade from old Scots Pines, the lighter green foliage and white trumpets of the Arum lilies, creamy scented freesias, golden, black-eyed Cape daisies, coral Cape Tulip and many more with familiar memories and colourful landscapes for many of us, all migrants.

Codner (1988) gives personal impressions of various lakes. In the context of this report, the most relevant is the telling contrast between descriptions of Thomsons Lake and South Lake - descriptions that are mandatory reading if the concept of urban lakes is to be developed.

> **Thomsons Lake:**
>
> The loveliest and most "wild" of the lakes. Surrounded by natural bush with wide sedge/reed beds this lake has room to breathe, to flood in winter and contract in summer without mocking man's improvements or damaging any installations. (The reference is to the fact that barbeques and cycle paths at Bibra were underwater at the time!)

South Lake:

> The sense of desolation here is profound. Man's inhumanity to the environment and to man can be seen and felt here with devastating clarity. The sterility and dreariness [are] indescribable.... Trees, bushes, creepers, groundcover, wildflowers and grasses, sedges and reeds have been replaced by reticulated rough grass, and an artificial peninsular into the larger of the 'lakes' bears eleven small weeping willows .. no wild thing dares to grow out of place.

From an aesthetic view, the diversity of the Jandakot wetlands is as interesting as it is relied upon for survival by wildlife. The challenge of Forrestdale, invaded by Arum lilies under the paperbarks, must be one of the most entrancing paradoxes that a strict conservationist will encounter. Should the invading Arum lilies be eradicated as being alien and foreign, non-native and a weed, or should they be enjoyed in all their exotic Victorian British glory?

The choice, gentle reader, is yours.

JANDAKOT GROUNDWATER SCHEME
STAGE 2

ENVIRONMENTAL CRITERIA
STUDY GROUP

VOLUME 2

Rare and Restricted Flora

PART F

Prepared For: Water Authority of Western Australia

Prepared by: E M Mattiske & B L Koch

March 1989

JANDAKOT MOUND - RARE AND RESTRICTED FLORA

A literature search of the rare, restricted or poorly collected native plant species was undertaken as part of the review of biological resources on the Jandakot Mound area.

In reviewing the literature for the area designated as the Jandakot Water Mound (i.e. southern Swan Coastal Plain), initially nineteen rare, restricted or poorly collected species were recognized as possibly occurring in the area (Rye and Hopper, 1981; Barrett, 1982; Patrick and Hopper, 1982; Rye, 1982; Anon, 1988), Table 1.

Marchant and Keighery (1979) and Leigh et al. (1981) were not consulted for this list as they are now considered to be out-dated. Also Leigh et al. (1984) is considered to be inaccurate for the West Australian flora.

All non-gazetted rare species were then checked against existing herbarium records at the Western Australian Herbarium. It was then possible to reduce the original list of nineteen species to fifteen species. This reduction resulted from the availability of new material; which increased their distribution range to greater than 160km (i.e. not restricted). Other changes to the original list include the following:

- Lysinema elegans has a more widespread distribution.
- Jacksonia gracilis (Barrett, 1982) has now become J. sericea.
- The number of collections of Tetraria australiensis has increased, changing it from rare to poorly collected.
- Dodonaea hackettiana was originally on the gazetted rare list and was collected from Thomson's Lake (Crook and Evans, 1981). It has now been withdrawn and is only considered to be restricted.

Only one species from the original list, Restio stenostachyus, was recorded during the permanent transect surveys located in the Jandakot Water Mound study area (E.M.Mattiske & Associates, 1989). This was reclassified to be non-restricted after consulting herbarium records.

Some six species on the list belong to the family - Orchidaceae. They generally flower from late August to November (A.Brown, pers. comm.). To maximize coverage of these species, any future botanical surveys in the area would need to be undertaken during these months.

Two of the plants were aquatics (Hydrocotyle lemnoides and Aponogeton hexatepalus) and therefore intensive surveys of the swamps and creeks would have to be carried out to determine the presence of these species in the Jandakot Mound area.

In general most botanical surveys only cover 50-70% of the flora in a given area. To date the surveys in the Jandakot Mound area have been limited in number to a few on the main reserves. Therefore with further studies a clearer view of the status of these rare, restricted and poorly collected species could be determined.

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TABLE 1. Summary of Conservation Status of Species on the Jandakot Mound.

	Rye 1982	Barrett 1982	Rye & Hopper 1981; Patrick & Hopper 1982	Anon 1988	W.A. Herbarium Status #
Aponogeton hexatepalus	-	D	Rare	Rare	-
Baumea arthrophylla	E	D	-	-	-
Billardiera parviflora var. guttata	-	D	-	-	D
Caladenia sp. (coastal plain) S.D.Hopper 3400	-	-	-	Rare	-
Diuris purdiei	-	E	Rare	Rare	-
Diuris sp. (Kwinana) A.P.Brown 10.9.84	-	-	-	Rare	-
Dodonaea hackettiana	E	B	Rare	Withdrawn	E
Drakaea jeanensis	-	B	-	Rare	-
Drakaea sp. (south west) S.D.Hopper 3566	-	-	-	Rare	-
Drosera occidentalis	E	D	Rare	Rare	-
Haloragis platycarpa	E	A	-	-	C
Hydrocotyle hispidula	E	D	-	-	-
Hydrocotyle lemnoides	E	B	Rare	Rare	-
Jacksonia sericea (synonym J.gracilis)	E	D	-	-	E
Lysinema elegans	E	D	-	-	F
*Restio stenostachyus	E	E	-	-	-
Stylidium utricularioides	E	E	-	-	-
Tetraria australiensis	-	B	-	-	D
Thelymitra hybrid (pauciflora x flexuosa)	-	D	-	-	D

* Species Recorded during Transect Surveys (E.M. Mattiske & Associates, 1989).

\# W.A. Herbarium Status - only assessed for non-gazetted rare species.

Classifications Used:

- Rye and Hopper (1981), Patrick and Hopper (1982) and Anon.(1988). Indicate Species gazetted as Rare.

- Barrett (1982), Rye (1982) and W.A. Herbarium Status use the same code, Viz.:
  - A - no specimens available
  - B - Rare (Apparently rare and quite restricted in distribution)
  - C - type specimen only
  - D - poorly collected (less than 5 collections)
  - E - restricted distribution of less than 100km
  - F - restricted distribution of less than 160km.

JANDAKOT GROUNDWATER SCHEME
STAGE 2

ENVIRONMENTAL CRITERIA
STUDY GROUP

VOLUME 2

Air Quality

PART G

Prepared For: Water Authority of Western Australia

Prepared by: P W Stephenson & Associates Pty Ltd

March 1989

TABLE OF CONTENTS

1.0 INTRODUCTION

Stephenson & Associates Pty Limited was requested by the Water Authority of Western Australia to perform a hydrogen sulfide (H_2S) atmospheric emission monitoring programme at their Mirrabooka and Jandakot Groundwater Treatment Works in Western Australia. Refer Brief presented as Appendix 9.

The objectives of this survey were:-

(i) To measure concentrations of H_2S adjacent to the Stage I groundwater aerators and hence determine ground level concentrations at various distances downwind from the aerators;

(ii) To provide a researched acceptable H_2S odour threshold for a residential area;

(iii) To determine the effectiveness of prechlorination as a method of H_2S odour control.

The H_2S monitoring programme was conducted on both the Mirrabooka and Jandakot sites. However, any observations or conclusions were to be applied to the Jandakot site in particular, as it is proposed that a second stage of the Jandakot well-field be developed to allow production to be almost doubled to 9.6×10^6 m^3 $year^{-1}$.

A further "southern" or third stage would increase production to 15.8×10^6 m^3 $year^{-1}$.

The processing of this additional water will result in increased gas emissions in a location in Jandakot which is presently subject to a rezoning action to permit residential development.

Hence it was necessary to determine at what distance from the GWTW the H_2S odour would be no longer detectable. This distance would then be proposed as a buffer zone between the treatment works and the residential development. Alternatively, some large-scale gas cleaning or treatment system would be required.

To reduce the H_2S emission at the source, the incoming raw water may be chlorinated prior to aeration. The cost of prechlorination is significant and must be balanced against the costs and benefits of installing air pollution control equipment or leaving reasonable buffer zones around the GWTW.

The emission monitoring site work was conducted during the week of 27th February to 4th March 1989 and co-ordinated with a sulfide in water monitoring programme conducted simultaneously by WAWA.

Currently Stage I of the Jandakot Groundwater Scheme consists of 15 unconfined and 2 artesian wells, which deliver approximately 5.3×10^6 m^3 $year^{-1}$ from the shallow aquifer to the public water supply system via the Jandakot GWTW. The treatment process consists of:-

- Aeration to remove dissolved carbon dioxide and hydrogen sulfide. The dissolved gases are released to the atmosphere in this process.
- Clarification to remove colour and turbidity.
- Filtration to remove any residual turbidity.

The aeration stage at Jandakot produces a noticeable H_2S odour in the immediate vicinity of the aerator.

2.0 AIR QUALITY CRITERIA - H_2S

Air quality criteria for ambient air pollutants have not been defined in Western Australia. While many of the effects of air pollution on materials, vegetation and visibility have been documented, the effects on health for some pollutants require further investigation under Australian conditions.

In the absence of specific data the following guidelines, goals and standards are presented:

- National Health and Medical Research Council (NH&MRC) Guidelines,
- World Health Organisation (WHO) Long Term Goals, and
- US Environmental Protection Agency (USEPA) Ambient Air Quality Standards.

These air quality criteria have been determined in light of international knowledge on the adverse effects of air pollutants on health. Damage to plants and materials and reduction to visibility have not been considered in their establishment.

The USEPA have not formulated a standard for H_2S, although some states individually have set recognised standards. These include:

California:	0.03 ppm	60 min (average)	
Minnesota:	(0.03 ppm	30 min (Av)	Not to be exceeded more than twice in any 5 consecutive days.
	(0.05 ppm	30 min (Av)	Not to be exceeded more than twice a year.
Montana:	"		"
Wyoming:	"		"

New Mexico:	0.003 ppm	30 min (Av)	
Texas:			
Residential)			
Recreation)	0.075 ppm	30 min (Av)	
Industrial	0.112 ppm	30 min (Av)	
Pennsylvania:	0.005 ppm	24 hr (Av))	This State is the
	0.1 ppm	60 min (Av))	only one that lists
		)	a 24 hr.

All standards are primary standards, defined by the USEPA as those necessary with adequate margin of safety to protect public health.

European countries have also set AAQS. Unlike the USA, most have a 24 hour averaging period as well as the shorter term (30-60 min). These include:

Bulgaria:	0.005 ppm	24 hrs (Av)	
	0.005 ppm	20 mins (Av)	
Canada:			
Alberta	0.002 ppm	24 hrs (Av)	
	0.009 ppm	60 mins (Av)	
	0.011 ppm	30 mins (Av)	
Manitoba	0.011 ppm	24 hrs (Av)	
	0.018 ppm	60 mins (Av)	
West Germany:	0.013 ppm	30 mins (Av)	Proposed Federal
	0.03 ppm	30 mins (Av)	Standard
Finland:	0.03 ppm	24 hrs (Av)	Not legal norms,
	0.1 ppm	30 mins (Av)	local health councils can enforce them

Israel:	0.03 ppm	24 hrs	(Av)	National AQS
	0.1 ppm	30 mins	(Av)	
Spain:	0.00025ppm	24 hrs	(Av)	Proposed standard
	0.006 ppm	30 mins	(Av)	

2.1 Odour Threshold - H_2S

2.1.1 Terminology

A clear consistent definition of threshold terminology is requisite in any effort to classify data. To this end, the appropriate terms as defined by the American Society for Testing and Materials (ASTM Designation E 253-67 T) have been used. They are:[1]

detection threshold, n - the minimum physical intensity detection by a subject where he or she is not required to identify the stimulus but just detect the existence of the stimulus.

difference threshold, n - the smallest physical difference between two stimuli which can be correctly identified as sensorially different. (The British Standard Institution puts it more simply: the smallest change in concentrations of a substance required to give a perceptible change.)

recognition threshold, n - the minimum physical intensity detected by a subject where he or she is required to identify the stimulus in some manner. (The British Standards Institution puts it more simply: the lowest concentration at which a substance is correctly identified.)

supra-threshold, n - above the threshold. Also called supraliminal.

threshold, absolute, n - the minimum physical intensity of stimulus that elicits a response a specified percent of the time. Synonym limen.

threshold, terminal, n - (1) the maximum intensity of a stimulus that will produce a given type of sensory experience without change in modality. (2) intensity of stimulation above which increase in intensity cannot be detected. (The British Standards Institution: the concentrations of a substance above which changes in concentration are not perceptible.)

Regrettably, international literature has not maintained a consistency in definitions with regard to odour threshold studies. Hence, there is a wide variation of published numerical values presented as odour thresholds.

2.1.2 Odour Thresholds - H_2S

Verschueren[2] in his Handbook of Environmental Data on Organic Chemicals has attempted to correlate the work of 26 separate studies into the odour threshold of H_2S. Figure 2.1 graphically presents his conclusion:

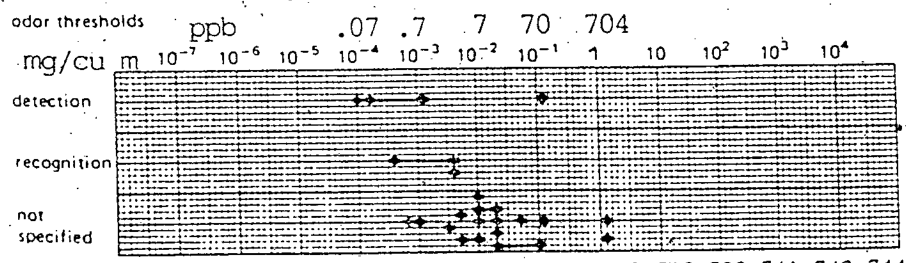
hydrogen sulfide

H_2S

A. PROPERTIES: colorless gas: m.w. 34.08; m.p. -83.8/-85.5°C; b.p. -60.2°C; v.p. 10 atm at -0.4°C, 20 atm at 25.5°C; v.d. 1.189 at 0°C

B. AIR POLLUTION FACTORS: 1 ppm = 1.42 mg/cu m, 1 mg/cu m = 0.704 ppm

–Odor: characteristic: quality: rotten egg odor



(71; 73; 170; 210; 279; 612; 616; 630; 644; 652; 677; 678; 710; 733; 741; 742; 744; 793; 801; 803; 821; 843; 857; 858; 863; 867) [3]-[27]

(316)

O.I. at 20°C = 17,000,000

FIGURE 2.1: Compilation of Odour Threshold Studies

- The majority of the odour thresholds appear to be in the range 1-10 parts per billion (ppb). There are, however, some thresholds both lower and higher than this range.

The American Society for Testing and Materials (ASTM) present a series of odour detection thresholds in their Compilation of Odor and Taste Threshold Values.[1]

These thresholds of detection range from 4.7 ppb to 0.6 ppm (parts per million).

The Victorian Environment Protection Authority in their State Environment Protection Policy (The Air Environment)[28] state in Schedule C for Class 2 indicators that the ground level concentration for H_2S is 0.1 ppb measured over a 3 minute mean. This standard was based on the Absolute Odour Threshold, that is, the majority of the odour panel can detect an odour but not specifically identify it.

However, a more reasonable approach in this instance would be the concept of Recognition Odour Threshold where all the panel can detect and identify the odour. A figure of 0.5 ppb for H_2S has been presented by some workers.

Hence, to maintain a reference point it is necessary to compare these odour thresholds with typical ambient air quality standards discussed previously. For example, in the U.S. Ambient Air Quality Standards (30 min Av.) there is a range of approximately 3-75 ppb H_2S. For other countries the range is from 5-30 ppb (24 hour Av.).

Therefore, it is proposed that a ground level concentration limit of 5 ppb be the considered standard.

2.2 Literature Search - H_2S Odour Emissions from Groundwater Treatment

A literature review of eight (8) international data bases was conducted to assess the work of others with respect to H_2S emissions from groundwater treatment plants and natural sources.

A reference list is presented at the end of this report.[29-47]

The data bases searched were:

- Enviroline - 1970 - December 1988
- Pollution Abstracts - 1970 - December 1988
- Aptic - 1966 - December 1988
- Environmental Bibliography - 1974 - December 1988
- NTIS - 1964 - 1988 (ISS12)
- Compendex - 1970 - December 1988
- CA Search - 1982 - December 1988
- Water Resources Abstracts - 1968 - March 1989

The searching of these data bases and the scanning of a number of others, including Australian data bases, produced very little, if any, information on H_2S emissions from GWTW. In fact, there does not appear to be a great deal of published information on emissions generally from GWTW Plants.

However, some information has been gleaned from the literature search - both with respect to H_2S emissions from groundwater and also from adjacent natural sources, such as swamps and marshes, which exist in fairly close proximity to both Mirrabooka and Jandakot GWTW.

H_2S is found in groundwater mainly as a result of anaerobic sulfate reduction.[39]

Many international papers referred to the contribution of sulfate leachates from improperly located or operated tips or landfill sites into the groundwater system. This increased level of sulfate in the groundwater led to a further increase in H_2S production in the groundwater.[37] It is understood such a problem does not currently exist in the Perth groundwater system.

The water supply for Pittsburg, Kansas (USA) is obtained from deep wells and contains 5 ppm H_2S. This is reduced to about 1 ppm by aeration, hence releasing 4 ppm into the atmosphere. [34] A similar situation occurs at both Mirrabooka and Jandakot GWTW.

South of Valdosta in Georgia (USA) water from the principal artesian aquifer contains as much as 3.6 ppm H_2S.[35]

Some workers have used reverse osmosis to remove salinity including dissolved H_2S and miscible hydrocarbons from groundwater.[42]

In New Mexico hydrogen peroxide was used as an oxidising agent to remove H_2S[43] from groundwater. Hydrogen peroxide was non-polluting and a relatively inexpensive oxidising agent. H_2S removal efficiencies of 95% and higher were reported.

Lochrane[46] reported using aeration and chlorination methods to remove H_2S from groundwater. Cost is proportional to percentage of H_2S removal required.

An experimental programme using carboxyl cation exchange to remove H_2S from ground water[47] has proved effective and economically feasible. The exchange capacity is dependent on selection of suitable catalysts and the use of the finer fraction of the cation exchanger.

Natural sources of H_2S included slow decomposition of organic matter in mangrove swamps, marshes and volcanic eruptions.

H_2S is emitted during sulfate reduction in freshwater sediments.[48]

These H_2S emissions from naturally occurring ground water contribute to the atmospheric sulfur cycle.[49,50,51]

Primary source of reduced sulfur compounds in marches is anaerobic production of H_2S by bacteria.

H_2S emission rates from swamps are higher during warmer months.[52,53,54]

H_2S levels in the atmosphere above swamps are highest during the night and decrease to a minimum during the day, generally related to atmospheric stability. Levels up to 12 ppb have been measured during early morning with a decrease to less than 0.5 ppb within 1 hour of sunrise.[55]

Hence, it can be concluded that in the presence of both Jandakot and Mirrabooka GWTW there may be natural sources of H_2S emissions from adjacent swamp areas.

3.0 RESULTS OF H_2S MONITORING PROGRAMME

All relevant monitoring results are presented in Tables 3.1 and 3.2 and Figures 3.1 - 3.5.

Table 3.1 presents airborne H_2S emission concentrations at the Jandakot aerator and correlates this data with sulfide monitoring in the feed water and plant operating conditions.

Table 3.2 presents similar data for a survey performed at Mirrabooka GWTW to assess the impact of chlorination prior to aeration.

Figures 3.1 - 3.4 present various measurement periods conducted at Jandakot GWTW between 27th February and 4th March 1989. Figure 3.4 is probably the most relevant for illustrating the dispersion of H_2S over distance from aerator.

Figure 3.5 presents measurements over distance with and without prechlorination.

Appendices 1 - 3 present measurements and investigations into sulfide concentration in water. Relevant sections of Appendix 1 are included in the Tables.

Appendices 7 and 8 present cumulative surface wind analyses data collected by Bureau of Meteorology. This data indicates that the sampling periods were conducted under a variety of typical meteorological conditions.

Measurements of wind speed and wind direction were made during each H_2S monitoring period and are included in both the Figures and the Tables.

As a further resource Appendix 4 presents continuous wind speed and wind direction measured at the Jandakot Airport during the survey period.

Appendices 5 and 6 present 12-month packages of historical (1980) wind speed, wind direction and Pasquill stability class (A to F) conducted by the Environment Protection Authority during their Kwinana Air Modelling Study at the Hope Base Meteorological Station and the Wattleup Station.

After much discussion it was concluded that the Hope Valley data was the most relevant to the Jandakot GWTW survey, one of the more significant reasons being the greater number of F stability class periods at Hope Valley, that is, the more stable air masses tend to inhibit satisfactory dispersion.

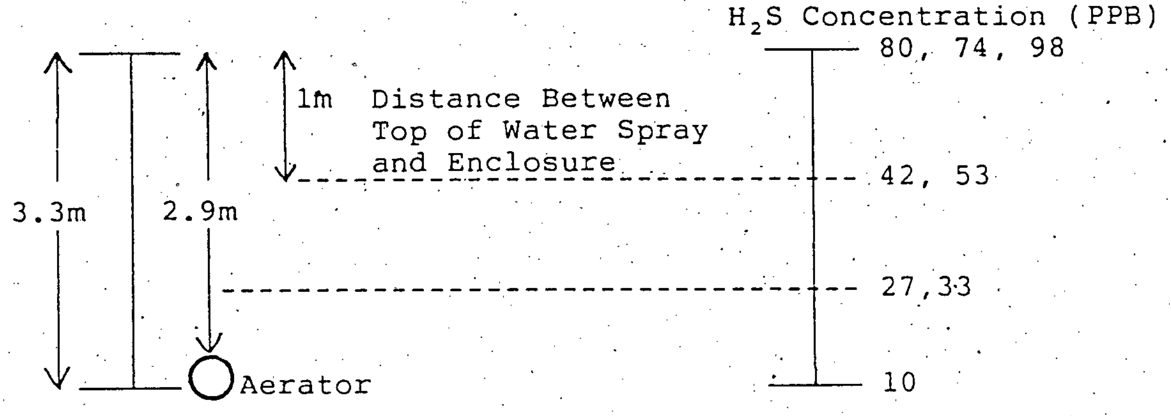
The aerator at Mirrabooka is located approximately 500 metres from the nearest residence to the West and nearest residences 275 metres to the East and 250 metres to the North East. The measurements conducted at Mirrabooka and presented in Figure 3.5 indicate that the dispersion of H_2S from source decreases generally linearly as plume travels up the hill from the aerator driven by whatever wind is present.

Once over the crest of the hill the rate of plume dispersion generally decreases and the plume is forced closer to ground level. Hence the ground level concentration of H_2S is still above the odour threshold at 520 metres.

These measurements are compared with the calculated dispersion ground level concentrations in Section 6 of this report.

A vertical profile of H_2S emission concentrations was also conducted at Mirrabooka. This indicated that the major H_2S emission occurs above the water sprayed from the aerators.

FIGURE 3.6: VERTICAL PROFILE OF H_2S EMISSION (MIRRABOOKA)



3.1 TEST METHODS AND EQUIPMENT

- Hydrogen Sulfide

  - Determined using direct reading Jerome Instruments Corporation Model 621, Hydrogen sulfide analyser utilising gold film membrane detection technique. Instrument detection limit is ± 1 ppb and range is 0-500 ppb.

  Sampling techniques were generally as Australian Standard 2330 - 1980 - Ambient Air - Determination of Hydrogen Sulfide - Automatic Intermittent sampling - Gas Chromatrographic method.

- Calibration

  - was performed using a CIG Special Gas Mixture of H_2S (88 ppm) and an Ecotech Dilution System.

- Wind Speed

  - Solomat 2000 fitted with vane anemometer probe (227MS).

- Temperature and Relative Humidity

  - Solomat 2000 fitted with hygrometer probe Model 355RH.

TABLE 3.1: SUMMARY OF MONITORING PROGRAMME (JANDAKOT)

DATE:		27 Feb.	28 Feb.	2 Mar.	3 Mar.	4 Mar.
DAY:		Mon.	Tues.	Thur.	Fri.	Sat.
SITE:		Jandakot GWTW	Jandakot GWTW	Jandakot GWTW	Jandakot GWTW	Jandakot GWTW
RAW WATER FEED RATE (ML/D):		17	19	21	23	28
No. OF AERATORS IN USE:		2	3	3	4	4
BORES ON LINE:		10,40,50,120, 140,45	10,40,50,60, 120,130,140,45	10,40,50,60, 120,130,140, 150,45,+30	10,20,30,40,50, 60,110,120,130, 140,150,45,105	10,20,30,40,50, 60,70,90,110, 120,130,140, 150,45
WIND SPEED (m/s):		≃ 4	2.5-4.5 (gusts → 7)	1030: 0.2-1.2 1130: 2.4-2.8 PM: 4-6	Calm - 1.5	Calm - 1.0
WIND DIRECTION:		N-NE	NW	1030: SE - S 1130: E - SE PM: SW	E	SW → SE
TEMPERATURE (°C):			26	29	27	23-26
RELATIVE HUMIDITY (%)			52	37	51	58
WATER (Refer Appendix 1 [Ref WAWA])						
pH	pre aerator	ND	ND	6.7	6.8	Not Determined
	post aerator	ND	ND	7.3	7.3	
Conductivity	pre aerator (mS/m)	ND	ND	96.7	94.6	
	post aerator (mS/m)	ND	ND	96.6	95.1	
Sulfide total	pre aerator (mg/L)	0.50	0.58	0.57	0.64	
	post aerator (mg/L)	0.20	0.22	0.20	0.30	
Sulfide dissolved	pre aerator (mg/L)	0.46	0.44	0.43	0.60	
	post aerator (mg/L)	0.19	0.20	0.17	0.25	
H_2S	pre aerator (mg/L)	0.30*	0.29	0.28	0.39	
	post aerator (mg/L)	0.07*	0.07	0.06	0.09	
AIR						
H_2S at source (aerator)	(ppb)	--		1300-2300	2500-3000	2300-2700
H_2S downwind	(ppb)	32-238	Refer Fig 3.1	Refer Fig 3.2	Refer Fig 3.3	Refer Fig 3.4
upwind	(ppb)	5-9				

TABLE 3.2: SUMMARY OF MONITORING PROGRAMME (MIRRABOOKA)

DATE:	1st March
DAY:	Wednesday
SITE:	Mirrabooka GWTW
RAW WATER FEED RATE:	35-41 ML/D
No. OF AERATORS IN USE:	5.5 out of total of 10
BORES ON LINE:	1A, 10, 26, 30, 35, 50, 300 172, 182, 262, 282, 285
WIND SPEED:	AM Calm PM 1 m/s
WIND DIRECTION:	AM NE ⟶ E PM SW

WATER (Refer Appendix 1 [Ref WAWA])

Sample Point	pH	Cond (ms/m)	Pre-Chlorine mg/L	Sulphide (mg/L)		H_2S (mg/L)
				Total	Dissolved	
Northern Main	6.1	48.1	Nil	0.96	0.29	0.26
Northern Main	5.9	45.7	8.0	0.03	0.04	0.03
Southern Main	6.1	44.8	Nil	0.89	0.20	0.18
Southern Main	6.1	47.8	8.0	0.69	0.67	0.62
Post Aerator	7.2	49.2	Nil	0.40	0.13	0.05
Post Aerator	7.5	51.4	8.0	0.05	0.01	0.003

AIR

H_2S at source (aerator) ppb (with prechlorination) 38-98
(without prechlorination) 2,200-7,300

For detail Refer Figure 3.5.

NOTES (associated with Tables 3.1 & 3.2)

*	Estimates of H_2S calculated using conductivity and pH from 2/3/89.
ND	Not determined.
+	Bore No.30 on line for 2.5 hours on 2/3/89.
ML/D	Megalitres (10^6 litre) per day.
m/s	Metres per second.
mg/L	Milligrams per litre.
ppb	Parts per billion.

4.0 OBSERVATIONS - H_2S MONITORING PROGRAMME

The following observations were made during the H_2S monitoring programme:-

- H_2S concentration emitted from the aerator enclosure varies with wind speed and direction.
- H_2S concentration varies with height of water spray from the aerator which varies with volume of raw feed water throughput. The closer the spray is to the top of the enclosure, the greater the H_2S emission out of the open top section of the aerator. At lower flow rates the greater H_2S emission concentration appears to be out of the sides of the aerator.
- H_2S concentration increases with increased raw water feed rate.
- H_2S odour tends to collect around the aerator enclosure and surrounding low lying areas during periods of no or low wind speed.
- Decrease in H_2S concentration from aerator over distance is not linear under this wind regime.
- H_2S odour is recognisable downwind but odorous gas tends to be stratified into a narrow band with very little lateral dispersion.
- H_2S was detected with the analyser at concentrations of 5-6 ppb at 350 and 520m downwind of the aerators at Jandakot and Mirrabooka respectively. The odour was detectable and, generally, recognisable as H_2S. These measurements were made without prechlorination.
- Odorous gases appear to be pushed out of the top of the aerator under low wind or calm conditions.

These gases are either:

- entrained by low velocity winds and drawn along the side of the aerator; or
- they rise up and are collected by cross winds which bring the gases to ground some distance away partially dispersed.

Prechlorination of raw feed water appears to have a significant effect on reducing odorous H_2S emissions from the aerators.

The reduction in H_2S appears to be of the order of 98% of the release rate at source. This reduction however does not translate directly at various increased distances from the plant (the periphery). At distances in excess of 350 metres from the source the reduction in H_2S appears to only be 60% of the release rate.

Private bores operated by local residents, particularly in the Jandakot area, tend to generate readily detectable levels of H_2S when used in garden sprinklers. These may contribute to the perceived reduction in H_2S collection efficiency at the periphery with prechlorination.

5.0 EFFICIENCY TRIAL - PRECHLORINATION

A prechlorination efficiency trial was performed on a single day on 1st March 1989 at Mirrabooka GWTW.

The following plant operating conditions applied:

- Chlorine feed rate of 8 mg/L in both incoming water channels.
- Raw feed water flow, however, was only 41 ML/D compared with a maximum flow of 90 ML/D; that is, plant was operating at less than half capacity.

Measurements of H_2S were made prior to commencement of prechlorination and then again during prechlorination.

The following maximum H_2S emission concentrations were measured adjacent to the downwind side of the aerator:

- Without Prechlorination - 2,200 - 7,300 ppb H_2S
- Start of Prechlorination but prior to Stabilisation - 600 - 1,000 ppb H_2S
- Prechlorination after Stabilisation - 38 - 98 ppb H_2S

TABLE 5.1: RAW FEED WATER ANALYSIS DURING PRECHLORINATION TRIAL - MIRRABOOKA GWTW

Sample Point	Pre Chlorination (mg/L)	H_2S (mg/L)	H_2S (mg/S)
Northern Main	Nil	0.26	120
" "	8.0	0.03	16
Southern Main	Nil	0.18	85(?)
" "	8.0	0.62	292(?)
Post Aerator	Nil	0.05	23
" "	8.0	0.003	1

Table 5.1 (Source: Appendix 1 WAWA - Refer Appendix 1 this report)

The data presented in Table 5.1 was collected from measurements of groundwater performed by WAWA during the H_2S emission survey. The water tests were "one-off" duplicate grab samples taken during the survey period. The sample point referred to as Southern Main should be ignored as this emission data appears inconsistent with the expected trends.

The Project brief mass emission rate of H_2S was given by WAWA as 80 mg/S without prechlorination. Hence, actual measurement levels are based on the above data (Table 5.1) whereas calculated g.l.c.'s are based on the 80 mg/S emission rate. (Refer Section 6.0 of this report.)

The conclusion drawn from this brief prechlorination trial was that prechlorination appeared to be 98% efficient in removing H_2S from the feed water when measured adjacent to the source (aerator).

This efficiency tended to decrease to 60% when measurements were made at the periphery or areas 300-500 metres downwind from the aerator enclosure.

6.0 DISPERSION OF H_2S

6.1 Method

The dispersion of H_2S emitted from the aerators was calculated using the Profile model which is a simple gaussian distribution model. The glc outputs from this model are based on 3-minute averaging times. This model tends to overpredict because it looks at the centre line concentration of the plume. Hence, it was necessary to check the calculations against actual measurements.

The brief for this project required determination of H_2S glc at various distances from the plant.

The brief did not, and has not, requested sophisticated dispersion modelling techniques such as ISC/EPA Model or AUSPLUME.

These models have and are still being proficiently and successfully operated by WA EPA. It would seem presumptuous to attempt to repeat the work of the EPA modelling section, one of Australia's best and internationally recognised dispersion modelling groups.

The dispersion calculations are based on the WAWA emission rates of H_2S as specified in the brief (Refer Appendix 9).

These emission rates, however, varied somewhat from the actual measured emission rates. Refer Appendix 1.

The variation in H_2S emission rate appeared to be generally caused by raw feed water flow volumes being below maximum, and variable wind speeds.

The Profile model was checked against actual measurements conducted on 1st March 1989 at a wind speed of 1-2 m/s and a stability class of C, if not D.

The 5-6 ppb cut-off point was measured at approximately 520 metres. After considering the discrepancies of actual H_2S mass emission rate being greater than calculated rate and the topography of the area to the North East of the plant, the correlation between calculated g.l.c.'s and measured g.l.c.'s is surprisingly good at Mirrabooka.

However, the correlation at Jandakot is not as close but more like the expected discrepancy between measured and calculated values. The factor of variation is approximately 5 times.

There are a range of reasons why this correlation is not close, not the least of which is that the actual measurements were conducted during early morning daylight hours when the wind speed was low and with a relatively stable atmosphere.

The following key to stability categories extracted from Turner's Workbook of Atmospheric Dispersion Estimates indicates that the only time a stable atmosphere will occur with low wind speeds is during a clear night.

The most stable atmosphere (Stability Class D) which will occur during the day will be one with more elevated wind speeds such as 5-6 m/s.

KEY TO STABILITY CATEGORIES

	DAY			NIGHT	
	INCOMING SOLAR RADIATION			CLOUD COVER	
SURFACE WIND SPEED AT 10 m (m/s)	STRONG	MODERATE	SLIGHT	MOSTLY OVERCAST	MOSTLY CLEAR
CLASS[a]	(1)	(2)	(3)	(4)	(5)
<2	*A*	*A–B*	*B*	*E*	*F*
2–3	*A–B*	*B*	*C*	*E*	*F*
3–5	*B*	*B–C*	*C*	*D*	*E*
5–6	*C*	*C–D*	*D*	*D*	*D*
>6	*C*	*D*	*D*	*D*	*D*

SOURCE: D. B. Turner. *Workbook of Atmospheric Dispersion Estimates*. Washington, D.C.: HEW, 1969.

[a] The neutral class, *D*, should be assumed for overcast conditions during day or night. Class *A* is the most unstable and class *F* is the most stable, with class *B* moderately unstable and class *E* slightly stable.

Hence, some discrepancy may be expected when attempting to compare daylight measurements with predicted ground level concentrations at low wind speeds with stable atmospheres.

6.2 Results and Discussion

The dispersion calculations are summarised in Tables 6.1 and 6.2 for Mirrabooka and Jandakot respectively. These tables present the distance from the source when the calculated ground level concentration (g.l.c.) is less than 5 ppb.

Tables 6.3 to 6.6 present the raw dispersion calculation results for:-

Table 6.3:	Mirrabooka	- H_2S mass emission of 80 mg/S
Table 6.4:	Jandakot(present)	- H_2S mass emission of 125 mg/S
Table 6.5:	Jandakot(Stage 2)	- H_2S mass emission of 250 mg/S
Table 6.6:	Jandakot(Southern Stages)	- H_2S mass emission of 420 mg/S

The calculated g.l.c.'s indicate that at the lowest H_2S mass emission rate of 80 mg/S at Mirrabooka there is:-

(1) Good correlation with measured data presented in Section 3.0.

(2) With efficient (98%) prechlorination the H_2S emission will be reduced to the point where a 500 metre buffer zone should be sufficient to reduce any emitted H_2S to less than the odour threshold at the outer limits of the buffer zone.

(3) However, with less efficient prechlorination, that is 60%, the buffer zone would need to be extended to 1.0-1.5 kilometres to attenuate the emission under very stable atmospheric conditions and low wind speeds.

Jandakot, on the other hand, with higher mass emission rates of H_2S will require 98% prechlorination efficiency to control the H_2S odour to satisfactory levels (5 ppb).

Even at this level of efficiency of H_2S removal, a minimum buffer zone of 500 metres will be required when Jandakot is developed to Southern Stages level.

It should be noted that these predictions are made under "worst case" conditions of low wind speed and stable atmospheric conditions.

Any lesser level of prechlorination will incur dramatic penalties in terms of buffer zone size, that is, 1.5 to greater than 2.0 kilometres radius.

TABLE 6.1: SUMMARY OF DISTANCE FROM SOURCE WHEN CALCULATED GROUND LEVEL CONCENTRATIONS OF H_2S ARE LESS THAN 5 PPB - MIRRABOOKA

(H_2S EMISSION RATE: 80 mg/s)

Wind Speed (m/s)	Distance from Source when g.l.c. is < 5 ppb (km)		
	Without Prechlorination	Prechlorination 60% Efficient	Prechlorination 98% Efficient
STABILITY CLASS D			
1.0	1.5	0.5-1.0	0.1-0.2
2.25	0.5-1.0	0.5	<0.1
3.75	0.5-1.0	0.3-0.4	<0.1
5.25	0.5	0.3	<0.1
6.75	0.4	0.2-0.3	<0.1
STABILITY CLASS E			
1.0	2.0	1.0-1.5	0.1-0.2
2.25	1.0-1.5	0.5-1.0	<0.1
3.75	0.5-1.0	0.5	<0.1
5.25	0.5-1.0	0.4	<0.1
6.75	0.5-1.0	0.3-0.4	<0.1
STABILITY CLASS F			
1.0	>2.0	2.0	0.2-0.3
2.25	2.0	1.0-1.5	0.1
3.75	1.5-2.0	0.5-1.0	<0.1
5.25	1.0-1.5	0.5-1.0	<0.1
6.75	1.0	0.5-1.0	<0.1

TABLE 6.2: SUMMARY OF DISTANCE FROM SOURCE WHEN CALCULATED GROUND LEVEL CONCENTRATIONS OF H_2S ARE LESS THAN 5 PPB - JANDAKOT

Wind Speed (m/s)	Distance from Source when g.l.c. is < 5 ppb (km)								
	125 mg H_2S/S			250 mg H_2S/S			420 mg H_2S/S		
	No Pre Cl_2	60% Pre Cl_2	98% Pre Cl_2	No Pre Cl_2	60% Pre Cl_2	98% Pre Cl_2	No Pre Cl_2	60% Pre Cl_2	98% Pre Cl_2
STABILITY CLASS D									
1.0	1.5-2.0	1.0	0.1-0.2	>2.0	1.5-2.0	0.2-0.3	>2.0	>2.0	0.3-0.4
2.25	1.0	0.5-1.0	0.1	1.5-2.0	1.0	0.1-0.2	> 2.0	1.0-1.5	0.2-0.3
3.75	0.5-1.0	0.4-0.5	<0.1	1.0-1.5	0.5-1.0	0.1-0.2	1.5-2.0	1.0	0.1-0.2
5.25	0.5-1.0	0.3-0.4	<0.1	1.0	0.5-1.0	<0.1	1.5	0.5-1.0	0.1-0.2
6.75	0.5-1.0	0.3	<0.1	0.5-1.0	0.4-0.5	<0.1	1.0-1.5	0.5-1.0	0.1-0.2
STABILITY CLASS E									
1.0	>2.0	1.5	0.2-0.3	>2.0	>2.0	0.3-0.4	>2.0	>2.0	0.4-0.5
2.25	1.5-2.0	0.5-1.0	0.1-0.2	>2.0	1.0-1.5	0.2-0.3	>2.0	2.0	0.3
3.75	1.0-1.5	0.5-1.0	<0.1	1.5-2.0	1.0	0.1-0.2	>2.0	1.0-1.5	0.2-0.3
5.25	0.5-1.0	0.5	<0.1	1.5	0.5-1.0	0.1-0.2	2.0	1.0-1.5	0.1-0.2
6.75	0.5-1.0	0.4-0.5	<0.1	1.0-1.5	0.5-1.0	0.1	1.5-2.0	1.0	0.1-0.2

TABLE 6.2: (cont'd)

Wind Speed (m/s)	Distance from Source when g.l.c. is < 5 ppb (km)								
	125 mg H_2S/S			250 mg H_2S/S			420 mg H_2S/S		
	No Pre Cl_2	60% Pre Cl_2	98% Pre Cl_2	No Pre Cl_2	60% Pre Cl_2	98% Pre Cl_2	No Pre Cl_2	60% Pre Cl_2	98% Pre Cl_2
STABILITY CLASS F									
1.0	>2.0	>2.0	0.3-0.4	>2.0	>2.0	0.5-1.0	>2.0	>2.0	0.5-1.0
2.25	>2.0	1.5-2.0	0.2	>2.0	>2.0	0.3-0.4	>2.0	>2.0	0.5
3.75	2.0	1.0-1.5	<0.1	>2.0	1.5-2.0	0.2-0.3	>2.0	>2.0	0.3-0.4
5.25	1.5-2.0	0.5-1.0	<0.1	>2.0	1.0-1.5	0.1-0.2	>2.0	2.0	0.1-0.2
6.75	1.5	0.5-1.0	<0.1	>2.0	1.0-1.5	0.1	>2.0	1.5-2.0	0.2-0.3

7.0 CONCLUSIONS

It is concluded from the H_2S measurements and dispersion calculations that a minimum buffer zone of 500 metres will be required if prechlorination is used. Prechlorination appears to reduce the H_2S emission by 98% at source and 60% at the periphery.

Without prechlorination the buffer zone would need to be increased from 0.5 to 1.5->2.0 kilometres at Jandakot. An increased cost penalty will be incurred for the extra chlorine required to treat the elevated H_2S emission.

It should be stressed, however, that the width of the buffer zone is somewhat irrelevant under adverse meteorological conditions, that is, calm or low wind speeds under a temperature inversion. This stable air mass will minimise dispersion of emitted pollutants, in particular, H_2S from an ostensibly ground level discharge.

This scenario coupled with the topography surrounding Jandakot GWTW indicate that the odorous gases will collect in the shallow valleys and remain there until the wind speed increases and/or the inversion breaks.

The wind pattern that will produce these conditions is most likely a light Easterly or valley drainage flow towards the coast. This meteorology typically occurs overnight or in the early morning.

Under these conditions the H_2S concentration may remain similar to that emitted from the aerator. This odour will be readily detectable by neighbouring residents.

The H_2S monitoring and research of international ambient air quality standards for H_2S indicate that 5 ppb would be a more reasonable goal in an area that has natural or uncontrolled sources of H_2S, e.g. private bores and low lying swampy land to the south of Jandakot GWTW and North East of Mirrabooka GWTW.

Generally, averaging times for ground level concentrations are set by the regulatory Authority, that is, EPA in WA. These limits tend to be goals to be achieved and may be negotiable with EPA prior to the final limit being set.

When assessing the cost effectiveness of prechlorination it is recommended that you investigate the feasibility of other forms of H_2S pollution control and possibly the concept of enclosing the aerator and venting the gases through a tall stack.

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FIGURES

FIGURE 3.1: H_2S MONITORING - JANDAKOT 28TH FEBRUARY 1989

(NOT TO SCALE)

SURVEY: 1330-1630 hrs.

All H_2S concentrations in ppb.

All Dimensions in metres.

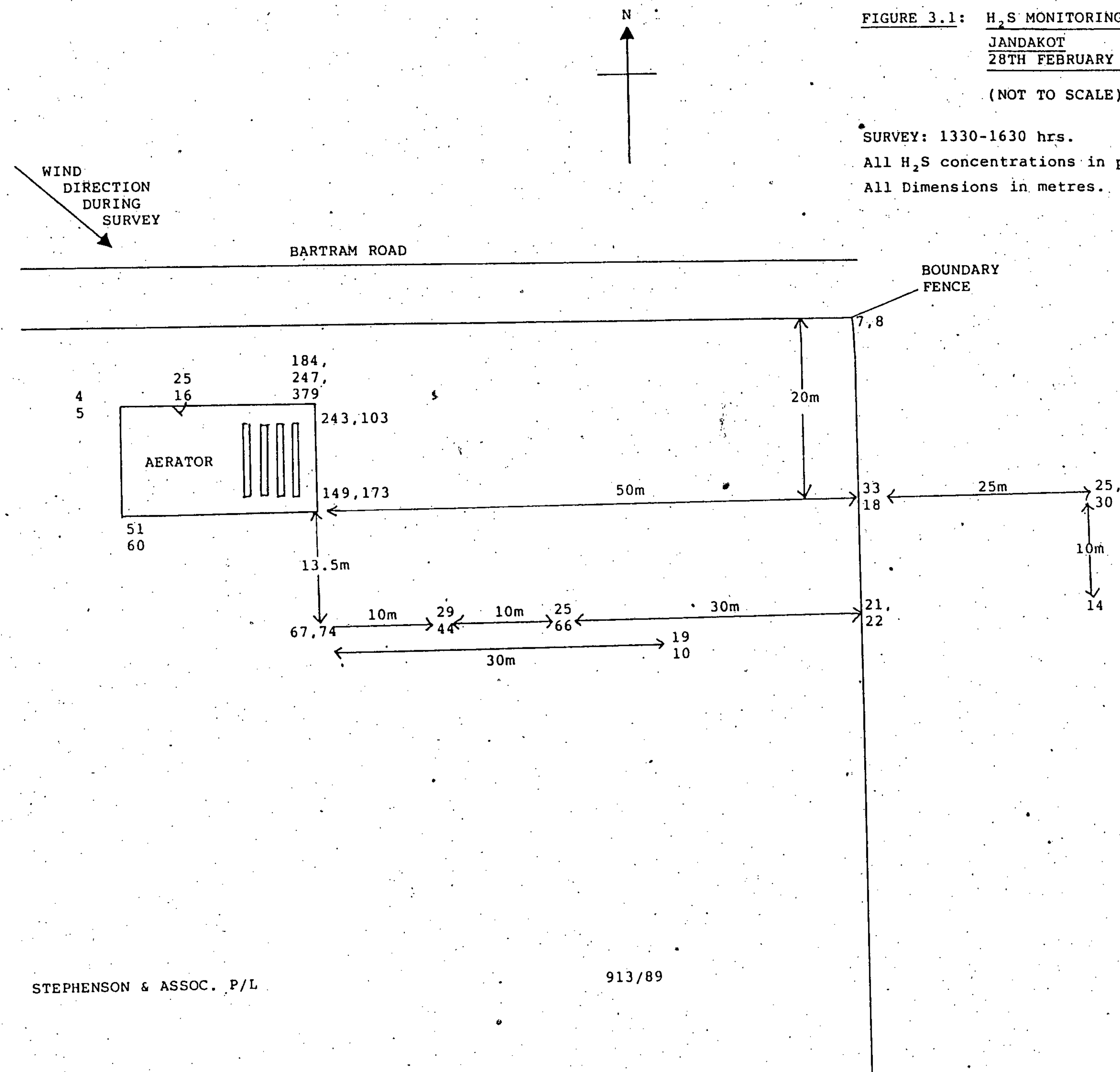

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FIGURE 3.2(i): H_2S MONITORING - JANDAKOT

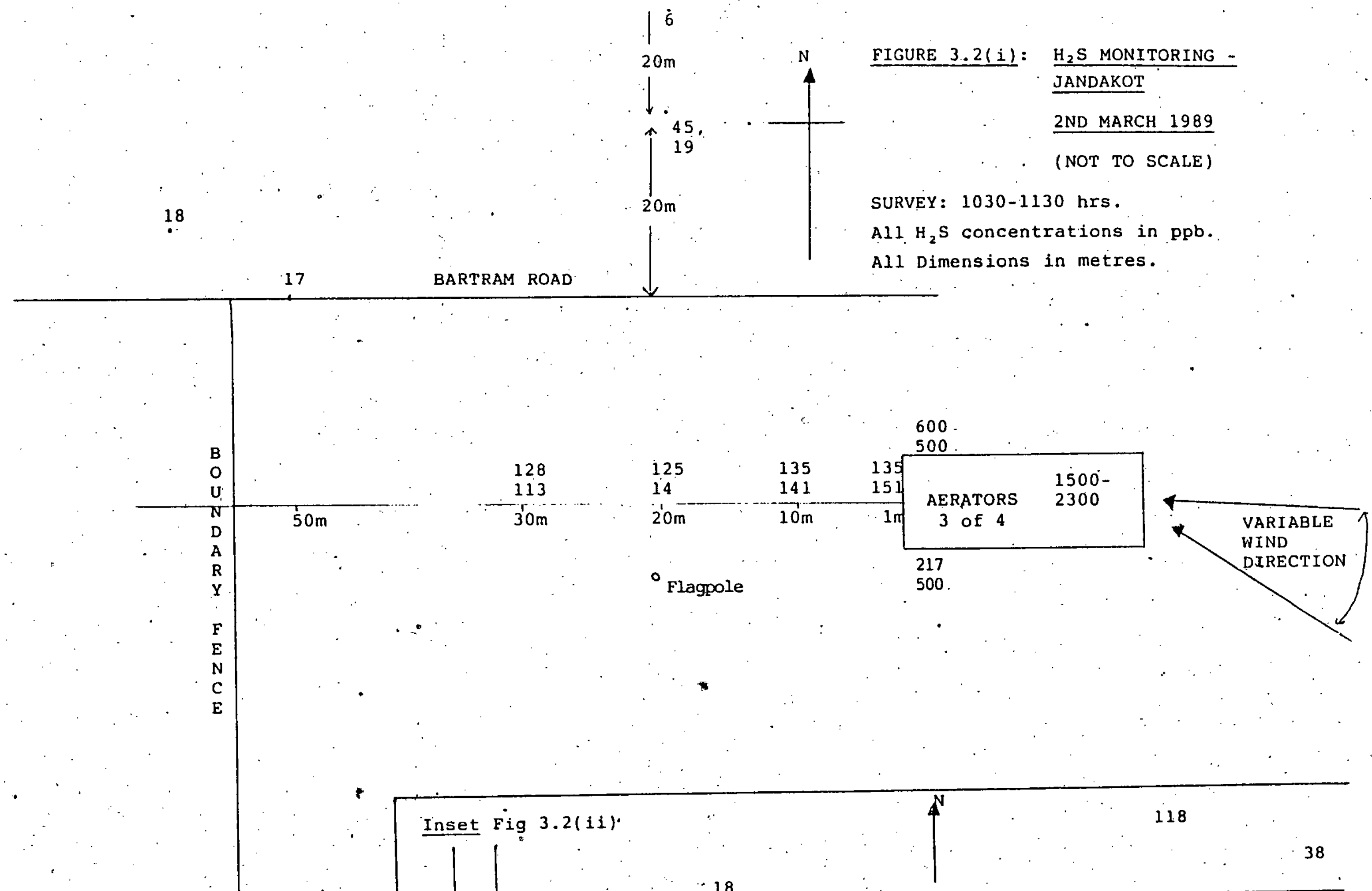
2ND MARCH 1989

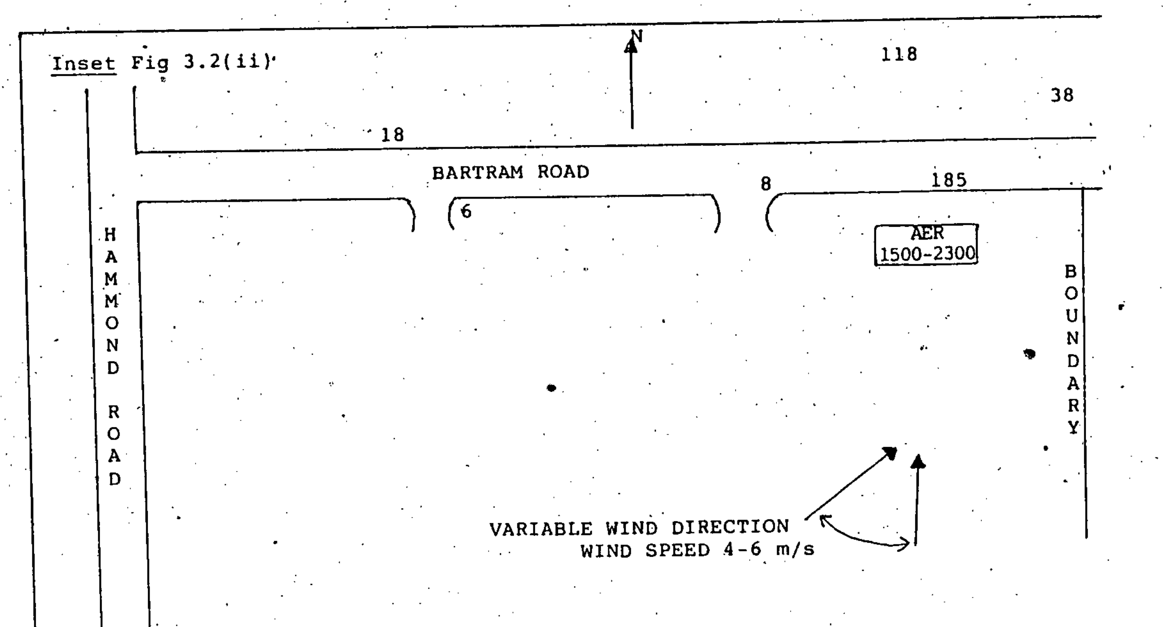
(NOT TO SCALE)

SURVEY: 1030-1130 hrs.

All H_2S concentrations in ppb.

All Dimensions in metres.





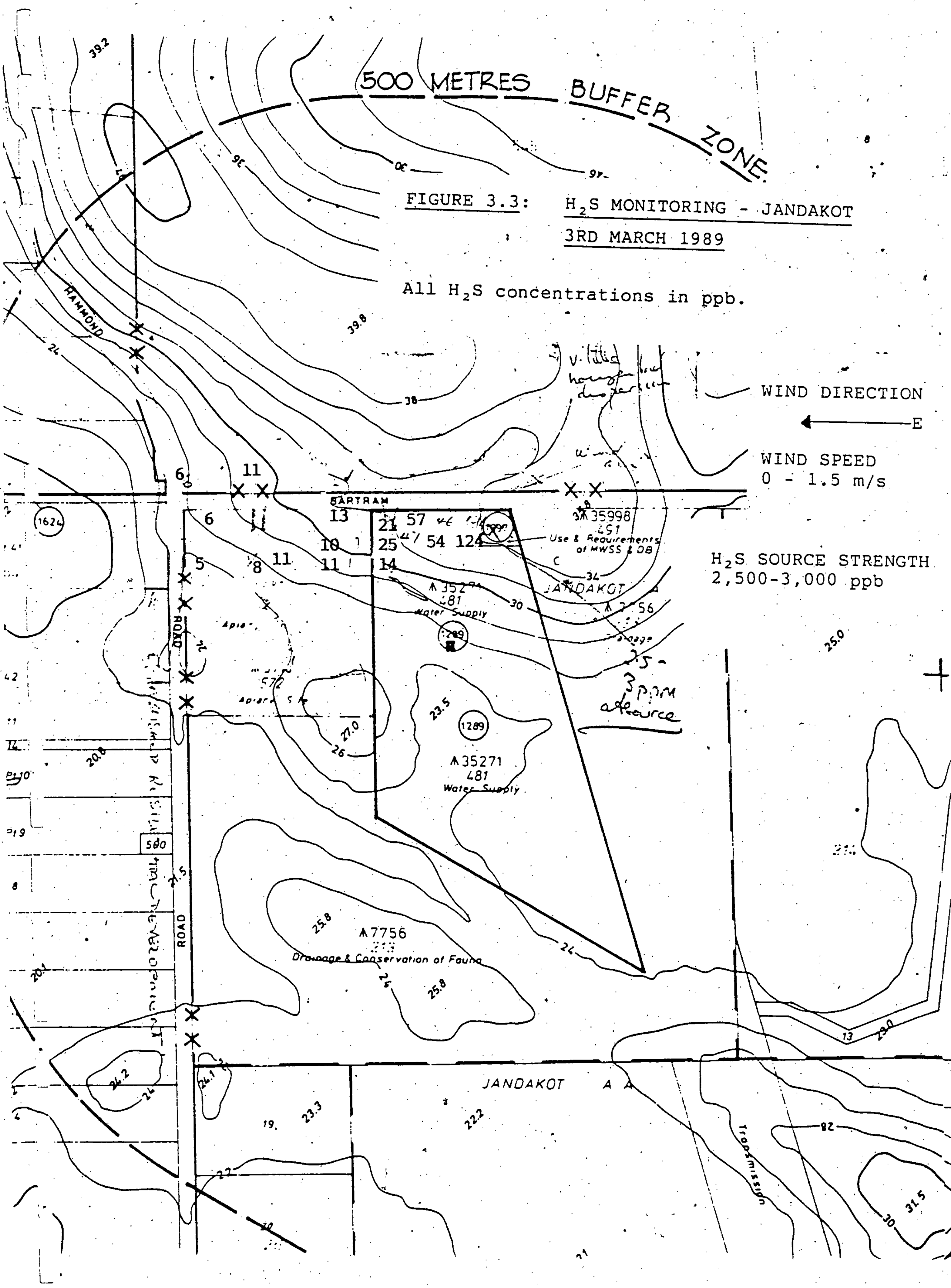
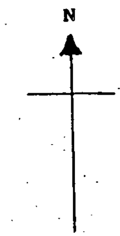


FIGURE 3.3: H_2S MONITORING - JANDAKOT
3RD MARCH 1989

FIGURE 3.4: H_2S MONITORING - JANDAKOT
4TH MARCH 1989
(NOT TO SCALE)

SURVEY: 0600-0900 hrs.
All H_2S concentrations in ppb.
All Dimensions in metres.



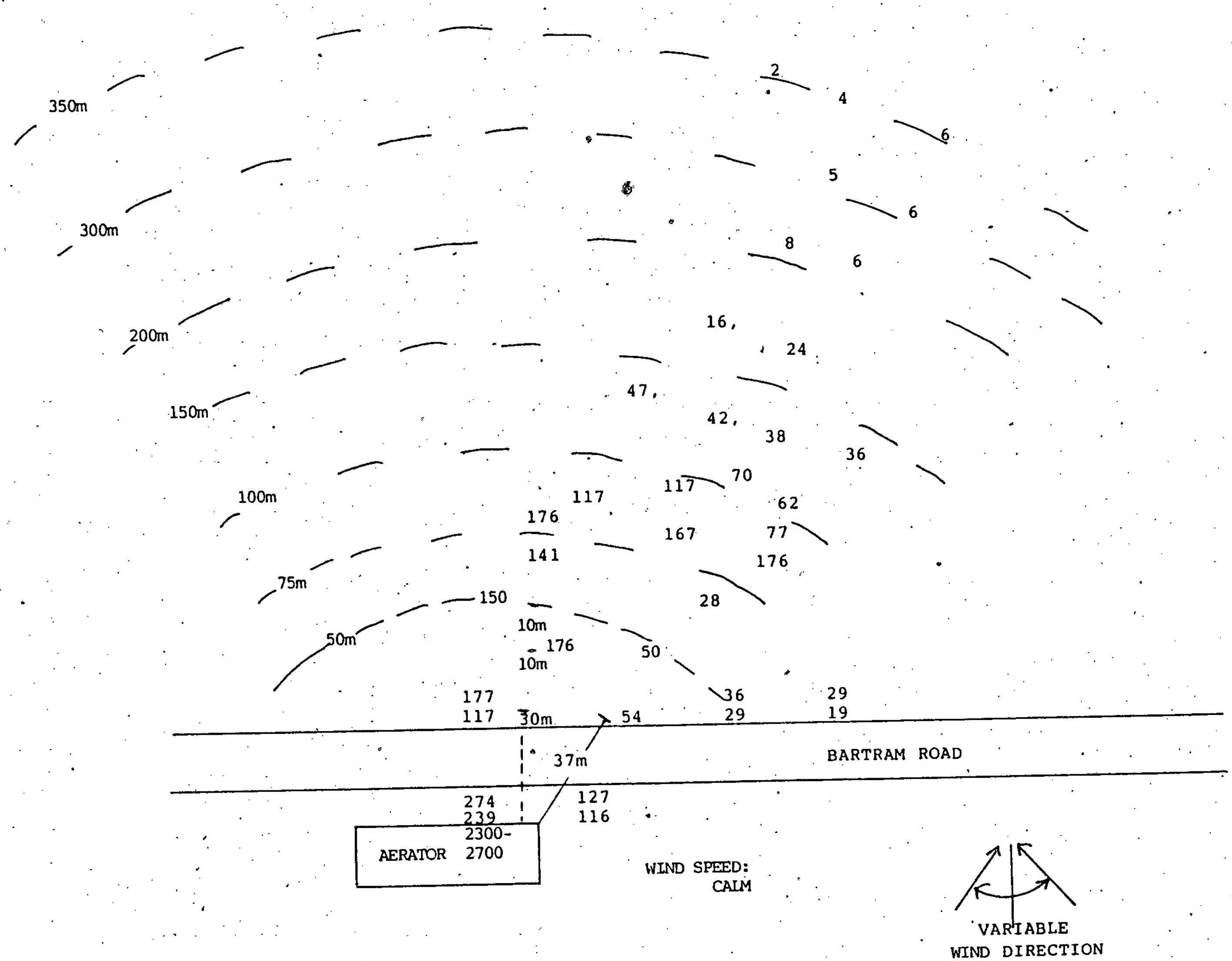
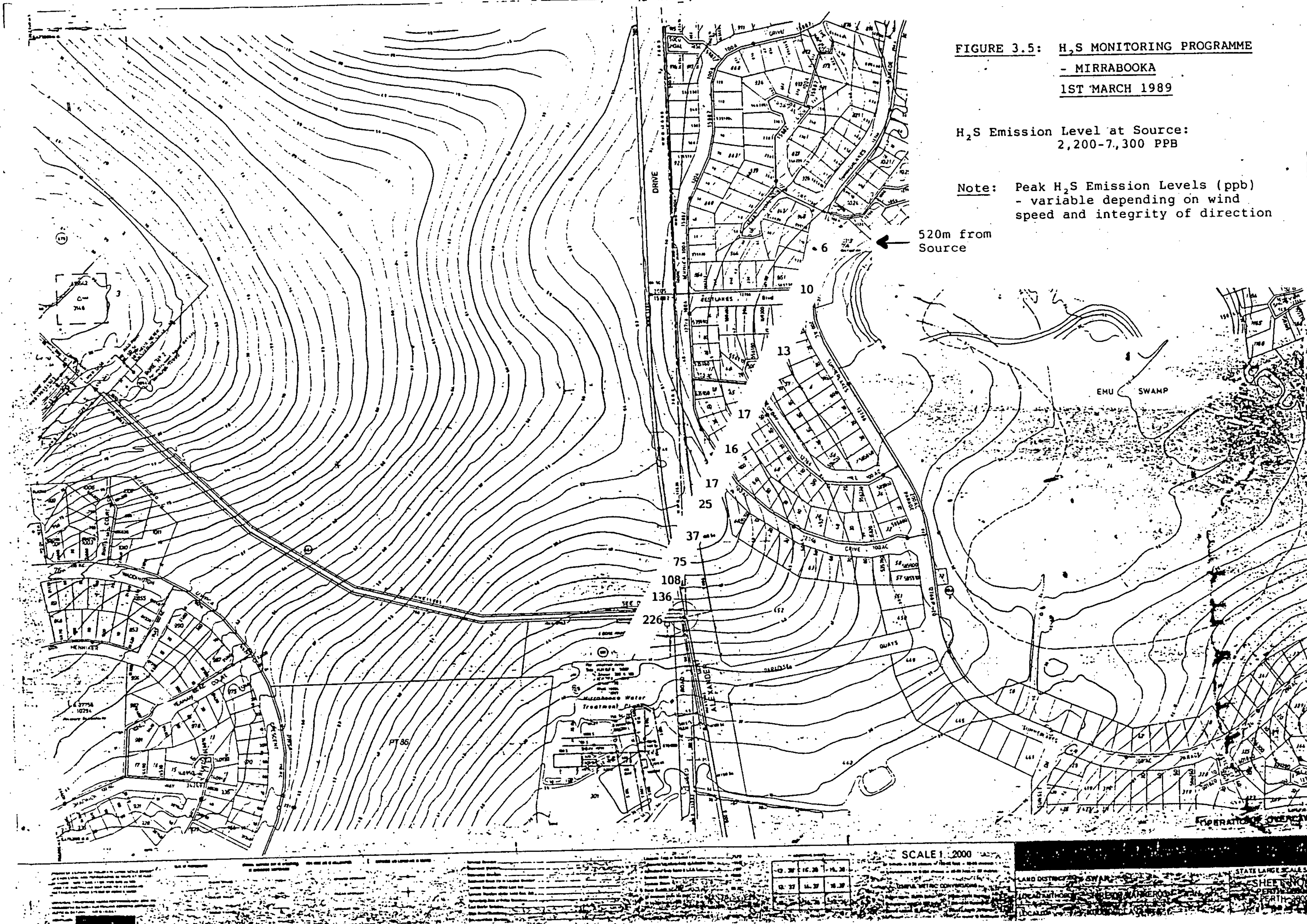


FIGURE 3.5: H_2S MONITORING PROGRAMME - MIRRABOOKA 1ST MARCH 1989

H_2S Emission Level at Source: 2,200-7,300 PPB

Note: Peak H_2S Emission Levels (ppb) - variable depending on wind speed and integrity of direction



TABLES

TABLE 6.3: H_2S DISPERSION CALCULATIONS

SITE: MIRRABOOKA GWTW

H_2S EMISSION RATE: 80 mg/S

Wind Speed (m/s)	1.0				2.25			3.75			5.25			6.75		
		Ground Level Concentration (parts per billion)														
Downwind Distance (km)	Raw Feed ug/m³	Raw Feed	Cl_2 60%	Cl_2 98%	Raw Feed	Cl_2 60%	Cl_2 98%	Raw Feed	Cl_2 60%	Cl_2 98%	Raw Feed	Cl_2 60%	Cl_2 98%	Raw Feed	Cl_2 60%	Cl_2 98%
STABILITY CLASS D																
0.1	462	333	133	6.66	148	59.3	2.96	89.0	35.6	1.78	63.5	25.4	1.27	49.4	19.8	0.99
0.2	151	109	43.5	2.18	48.4	19.3	0.97	29.0	11.6	0.58	20.7	8.32	0.42	16.1	6.46	0.32
0.3	74.9	53.9	21.6	1.08	23.9	9.60	0.48	14.4	5.75	0.29	10.2	4.11	0.20	8.00	3.19	0.16
0.4	45.5	32.8	13.1	0.66	14.6	5.84	0.29	8.77	3.50	0.17	6.25	2.50	0.13	4.86	1.95	0.10
0.5	32.8	23.6	9.47	0.47	10.5	4.20	0.21	6.30	2.52	0.13	4.50	1.80	0.09	3.50	1.40	0.07
1.0	10.5	7.55	3.02	0.15	3.35	1.34	0.07	2.02	0.81	0.04	1.44	0.58	0.03	1.12	0.45	0.03
1.5	6.34	4.57	1.83	0.09	2.03	0.81	0.04	1.22	0.49	0.03	0.87	0.35	0.02	0.68	0.27	0.01
2.0	3.49	2.52	1.00	0.05	1.12	0.45	0.03	0.67	0.27	0.01	0.48	0.19	0.01	0.37	0.15	0.006
STABILITY CLASS E																
0.1	636	458	184	9.15	204	81.3	4.07	122	48.9	2.44	87.0	34.9	1.75	67.8	27.1	1.36
0.2	273	196	78.7	3.94	87.0	34.9	1.75	52.4	21.0	1.05	37.4	15.0	0.75	29.1	11.6	0.58
0.3	143	102	41.1	2.05	45.5	18.2	0.91	27.3	10.9	0.54	19.5	7.81	0.39	15.2	6.07	0.30
0.4	83.8	60.3	24.1	1.21	26.8	10.8	0.54	16.1	6.46	0.32	11.5	4.60	0.23	8.96	3.57	0.18
0.5	54.6	39.4	15.7	0.79	17.5	6.98	0.35	10.5	4.20	0.21	7.49	3.00	0.15	5.83	2.33	0.12
1.0	19.8	14.3	5.72	0.29	6.34	2.53	0.13	3.81	1.52	0.08	2.72	1.09	0.06	2.11	0.84	0.04
1.5	10.5	7.62	3.03	0.15	3.37	1.35	0.07	2.02	0.81	0.04	1.45	0.58	0.03	1.13	0.45	0.03
2.0	6.41	4.62	1.85	0.09	2.05	0.82	0.04	1.24	0.49	0.03	0.88	0.35	0.02	0.68	0.28	0.01
STABILITY CLASS F																
0.1	662	477	191	9.54	212	84.5	4.24	127	50.9	2.54	90.9	36.4	1.82	70.4	28.3	1.41
0.2	465	335	134	6.72	149	59.6	2.98	89.6	35.8	1.79	63.9	25.6	0.51	49.7	19.9	0.99
0.3	266	192	76.8	3.84	85.1	34.1	1.71	51.2	20.5	1.02	36.5	14.7	0.73	28.4	11.4	0.57
0.4	179	129	51.4	2.57	57.2	22.8	1.15	34.3	13.7	0.68	24.5	9.79	0.49	19.1	7.62	0.38
0.5	136	97.9	39.0	1.95	43.5	17.4	0.87	26.1	10.4	0.52	18.6	7.49	0.37	14.5	5.80	0.29
1.0	44.8	32.3	12.9	0.65	14.3	5.73	0.29	8.58	3.44	0.17	6.14	2.46	0.12	4.78	1.91	0.10
1.5	27.6	19.9	7.94	0.40	8.83	3.54	0.18	5.31	2.12	0.11	3.79	1.52	0.08	2.95	1.18	0.06
2.0	16.3	11.7	4.69	0.24	5.20	2.08	0.10	3.12	1.25	0.03	2.23	0.89	0.04	1.73	0.69	0.03

NOTES:

Raw feed - No prechlorination
Cl_2 - Prechlorination
60% - 60% removal efficiency
98% - 98% removal efficiency
m/s - metres per second

TABLE 6.4: H_2S DISPERSION CALCULATIONS

SITE: JANDAKOT GWTW

H_2S EMISSION RATE: 125 mg/S

Wind Speed (m/s)	1.0				2.25			3.75			5.25			6.75		
					Ground Level Concentration (parts per billion)											
Downwind Distance (km)	Raw Feed ug/m³	Raw Feed	Cl_2 60%	Cl_2 98%	Raw Feed	Cl_2 60%	Cl_2 98%	Raw Feed	Cl_2 60%	Cl_2 98%	Raw Feed	Cl_2 60%	Cl_2 98%	Raw Feed	Cl_2 60%	Cl_2 98%
STABILITY CLASS D																
0.1	722	521	208	10.4	232	92.6	4.63	139	55.6	2.78	99.2	39.7	1.99	77.2	30.9	1.54
0.2	236	170	68.0	3.40	75.6	30.2	1.51	45.3	18.1	0.91	32.4	13.0	0.65	25.2	10.1	0.50
0.3	117	84.2	33.7	1.68	37.4	15.0	0.75	22.5	8.98	0.45	16.0	6.42	0.32	12.5	4.99	0.25
0.4	71.1	51.3	20.5	1,03	22.8	9.12	0.46	13.7	5.47	0.27	9.77	3.91	0.20	7.60	3.04	0.15
0.5	51.2	36.9	14.8	0.74	16.4	6.56	0.33	9.84	3.94	0.20	7.03	2.81	0.14	5.47	2.19	0.11
1.0	16.4	11.8	4.72	0.24	5.24	2.10	0.11	3.15	1.26	0.06	2.25	0.90	0.04	1.75	0.70	0.04
1.5	9.90	7.14	2.86	0.14	3.17	1.27	0.06	1.90	0.76	0.04	1.36	0.54	0.03	1.06	0.42	0.02
2.0	5.45	3.93	1.57	0.08	1.75	0.70	0.04	1.05	0.42	0.02	0.75	0.30	0.02	0.58	0.23	0.01
STABILITY CLASS E																
0.1	994	716	287	14.3	318	127	6.36	191	76.4	3.82	136	54.6	2.73	106	42.4	2.12
0.2	426	307	123	6,15	136	54.6	2.73	81.9	32.8	1.64	58.5	23.4	1.17	45.5	18.2	0.91
0.3	223	160	64.2	3.21	71.1	28.4	1.42	42.7	17.1	0.85	30.5	12.2	0.61	23.7	9.48	0.47
0.4	131	94.2	37.7	1.89	41.9	16.8	0.84	25.1	10.1	0.50	17.9	7.18	0.36	14.0	5.58	0.28
0.5	85.3	61.5	24.6	1.23	27.3	10.9	0.55	16.4	6.56	0.33	11.7	4.69	0.23	9.11	3.64	0.18
1.0	31.0	22.3	8.94	0.45	9.91	3.96	0.20	5.95	2.38	0.12	4.25	1.70	0.09	3.30	1.32	0.07
1.5	16.4	11.9	4.74	0.24	5.27	2.11	0.11	3.16	1.26	0.06	2.26	0.90	0.05	1.76	0.70	0.04
2.0	10.0	7.22	2.89	0.14	3.21	1.28	0.06	1.93	0.77	0.04	1.38	0.55	0.03	1.07	0.43	0.02
STABILITY CLASS F																
0.1	1,034	745	298	14.9	331	132	6.62	199	79.5	3.97	142	56.8	2.84	110	44.2	2.21
0.2	727	524	210	10.5	233	93.2	4.66	140	55.9	2.80	99.8	39.9	0.80	77.6	31.1	1.55
0.3	416	300	120	6.00	133	53.3	2.67	80.0	32.0	1.60	57.1	22.9	1.14	44.4	17.8	0.89
0.4	279	201	80.3	4.02	89.3	35.7	1.79	53.6	21.4	1.07	38.3	15.3	0.77	29.8	11.9	0.60
0.5	212	153	61.0	3.05	68	27.2	1.36	40.8	16.3	0.82	29.1	11.7	0.58	22.7	9.07	0.45
1.0	70.0	50.4	20.2	1.01	22.4	8.96	0.45	13.4	5.38	0.27	9.60	3.84	0.19	7.47	2.99	0.15
1.5	43.1	31.1	12.4	0.62	13.8	5.53	0.28	8.29	3.32	0.17	5.92	2.37	0.12	4.61	1.84	0.09
2.0	25.4	18.3	7.33	0.37	8.13	3.25	0.16	4.88	1.95	0.04	3.49	1.39	0.07	2.71	1.08	0.05

NOTES:

Raw feed - No prechlorination
Cl_2 - Prechlorination
60% - 60% removal efficiency
98% - 98% removal efficiency
m/s - metres per second

TABLE 6.5: H_2S DISPERSION CALCULATIONS

SITE: JANDAKOT GWTW STAGE 2

H_2S EMISSION RATE: 250 mg/S

Wind Speed (m/s)	1.0				2.25			3.75			5.25			6.75		
		Ground Level Concentration (parts per billion)														
Downwind Distance (km)	Raw Feed ug/m³	Raw Feed	Cl_2 60%	Cl_2 98%	Raw Feed	Cl_2 60%	Cl_2 98%	Raw Feed	Cl_2 60%	Cl_2 98%	Raw Feed	Cl_2 60%	Cl_2 98%	Raw Feed	Cl_2 60%	Cl_2 98%
STABILITY CLASS D																
0.1	1,444	1,042	416	20.8	464	185	9.26	278	111	5.56	198	79.4	3.98	154	61.8	3.08
0.2	472	340	136	6.80	151	60.4	3.02	90.6	36.2	1.82	64.8	26.0	1.30	50.4	20.2	1.00
0.3	234	168	67.4	3.36	74.8	30.0	1.50	45.0	18.0	0.90	32.0	12.8	0.64	25.0	9.98	0.50
0.4	142	103	41.0	2.06	45.6	18.2	0.92	27.4	10.9	0.54	19.5	7.82	0.40	15.2	6.08	0.30
0.5	102	73.8	29.6	1.48	32.8	13.1	0.66	19.7	7.88	0.40	14.1	5.62	0.28	10.9	4.38	0.22
1.0	32.8	23.6	9.44	0.48	10.5	4.20	0.22	6.30	2.52	0.12	4.50	1.80	0.08	3.50	1.40	0.08
1.5	19.8	14.3	5.72	0.28	6.34	2.54	0.12	3.80	1.52	0.08	2.72	1.08	0.06	2.12	0.84	0.04
2.0	10.9	7.86	3.14	0.16	3.50	1.40	0.08	2.10	0.84	0.04	1.50	0.60	0.04	1.16	0.46	0.02
STABILITY CLASS E																
0.1	1,988	1,432	574	28.6	636	254	12.7	382	153	7.64	272	109	5.46	212	84.8	4.24
0.2	852	614	246	12.3	272	109	5.46	164	65.6	3.28	117	46.8	2.34	91.0	36.4	1.82
0.3	446	320	128	6.42	142	56.8	2.84	85.4	34.2	1.70	61.0	24.4	1.22	47.4	19.0	0.94
0.4	262	188	75.4	3.78	83.8	33.6	1.68	50.2	20.2	1.00	35.8	14.4	0.72	28.0	11.2	0.56
0.5	171	123	49.2	2.46	54.6	21.8	1.10	32.8	13.1	0.66	23.4	9.38	0.46	18.2	7.28	0.36
1.0	62.0	44.6	17.9	0.90	19.8	7.92	0.40	11.9	4.76	0.24	8.50	3.40	0.18	6.60	2.64	0.14
1.5	32.9	23.8	9.48	0.48	10.5	4.22	0.22	6.32	2.52	0.12	4.52	1.80	0.10	3.52	1.40	0.08
2.0	20.0	14.4	5.78	0.28	6.42	2.56	0.12	3.86	1.54	0.08	2.76	1.10	0.06	2.14	0.86	0.04
STABILITY CLASS F																
0.1	2,068	1,490	596	29.8	662	264	13.2	398	159	7.94	284	114	5.68	220	88.4	4.42
0.2	1,454	1,048	420	21.0	466	186	9.32	280	112	5.60	200	79.8	1.60	155	62.2	3.10
0.3	832	600	240	12.0	266	107	5.34	160	64.0	3.20	114	45.8	2.28	88.8	35.6	1.78
0.4	558	402	161	8.04	179	71.4	3.58	107	42.8	2.14	76.6	30.6	1.54	59.6	23.8	1.20
0.5	424	306	122	6.10	136	54.4	2.72	81.6	32.6	1.64	58.2	23.4	1.16	45.4	18.1	0.90
1.0	140	101	40.4	2.02	44.8	17.9	0.90	26.8	10.8	0.54	19.2	7.68	0.38	14.9	5.98	0.30
1.5	86.2	62.2	24.8	1.24	27.6	11.1	0.56	16.6	6.64	0.34	11.8	4.74	0.24	9.22	3.68	0.18
2.0	50.8	36.6	14.7	0.74	16.3	6.50	0.32	9.76	3.90	0.08	6.98	2.78	0.14	5.42	2.16	0.10

NOTES:

Raw feed - No prechlorination
Cl_2 - Prechlorination
60% - 60% removal efficiency
98% - 98% removal efficiency
m/s - metres per second

TABLE 6.6: H_2S DISPERSION CALCULATIONS

SITE: JANDAKOT GWTW SOUTHERN STAGES

H_2S EMISSION RATE: 420 mg/S

Wind Speed (m/s)	1.0				2.25			3.75			5.25			6.75		
	Ground Level Concentration (parts per billion)															
Downwind Distance (km)	Raw Feed ug/m³	Raw Feed	Cl_2 60%	Cl_2 98%	Raw Feed	Cl_2 60%	Cl_2 98%	Raw Feed	Cl_2 60%	Cl_2 98%	Raw Feed	Cl_2 60%	Cl_2 98%	Raw Feed	Cl_2 60%	Cl_2 98%
STABILITY CLASS D																
0.1	2,426	1,751	699	34.9	780	311	15.6	467	187	9.34	333	133	6.69	259	104	5.17
0.2	793	571	228	11.4	254	101	5.07	152	60.8	3.06	109	43.7	2.18	84.7	33.9	1.68
0.3	393	283	113	5.64	126	50.4	2.52	75.6	30.2	1.51	53.8	21.6	1.08	42.0	16.8	0.84
0.4	239	172	68.9	3.46	76.6	30.6	1.55	46.0	18.4	0.91	32.8	13.1	0.67	25.5	10.2	0.50
0.5	172	124	49.7	2.49	55.1	22.0	1.11	33.1	13.2	0.67	23.6	9.44	0.47	18.4	7.36	0.37
1.0	55.1	39.6	15.9	0.81	17.6	7.06	0.37	10.6	4.23	0.20	7.56	3.02	0.13	5.88	2.35	0.13
1.5	33.3	24.0	9.61	0.47	10.7	4.27	0.20	6.38	2.55	0.13	4.57	1.81	0.10	3.56	1.41	0.07
2.0	18.3	13.2	5.28	0.27	5.88	2.35	0.13	3.53	1.41	0.07	2.52	1.01	0.07	1.95	0.77	0.03
STABILITY CLASS E																
0.1	3,340	2,406	964	48.0	1068	427	21.4	642	257	12.8	457	183	9.17	356	142	7.12
0.2	1,431	1,032	413	20.7	457	183	9.17	275	1102	5.51	197	78.6	3.93	153	61.2	3.06
0.3	749	538	216	10.8	239	95.4	4.77	143	57.5	2.86	102	41.0	2.05	79.6	31.9	1.58
0.4	440	317	127	6.35	141	56.4	2.82	84.3	33.9	1.68	60.1	24.1	1.21	47.0	18.7	0.94
0.5	287	207	82.7	4.13	91.7	36.6	1.85	55.1	22.0	1.11	39.3	15.8	0.77	30.6	12.2	0.60
1.0	104	74.9	30.0	1.51	33.3	13.3	0.67	20.0	8.00	0.40	14.3	5.71	0.30	11.1	4.44	0.24
1.5	55.2	40.0	15.9	0.81	17.7	7.09	0.37	10.6	4.23	0.20	7.59	3.02	0.17	5.91	2.35	0.13
2.0	33.6	24.3	9.71	0.47	10.8	4.30	0.20	6.48	2.59	0.13	4.64	1.85	0.10	3.60	1.44	0.07
STABILITY CLASS F																
0.1	3,474	2,503	1001	50.1	1112	444	22.2	669	267	13.3	477	191	9.54	370	149	7.43
0.2	2,443	1,761	706	35.3	783	313	15.7	470	188	9.41	335	134	2.69	261	104	5.21
0.3	1,398	1,008	403	20.2	447	179	8.97	269	108	5.38	192	76.9	3.83	149	59.8	2.99
0.4	937	675	270	13.5	300	120	6.01	180	71.9	3.60	129	51.4	2.59	100	40.0	2.02
0.5	712	514	205	10.2	228	91.4	4.57	137	54.8	2.76	97.8	39.3	1.95	76.3	30.5	1.51
1.0	235	169	67.9	3.39	75.3	30.1	1.51	45.0	18.1	0.91	32.3	12.9	0.64	25.1	10.0	0.50
1.5	145	104	41.7	2.08	46.4	18.6	0.94	27.9	11.2	0.57	19.9	7.96	0.40	15.5	6.18	0.30
2.0	85.3	61.5	24.6	1.24	27.3	10.9	0.54	16.4	6.55	0.13	11.7	4.67	0.24	9.11	3.63	0.17

NOTES:

Raw feed - No prechlorination
Cl_2 - Prechlorination
60% - 60% removal efficiency
98% - 98% removal efficiency
m/s - metres per second