Study of Ecological Water Requirements on the Gnangara and Jandakot Mounds under Section 46 of the Environmental Protection Act.

Tasks 3 & 5: Parameter Identification and Monitoring Program Review

Prepared for:
Water and Rivers Commission

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EXECUTIVE SUMMARY

Introduction

The objectives of this report are to:

- propose environmental and biological condition indicators that reflect environmental values and have a defined relationship with groundwater levels and could be used together with water criteria within a management framework, as management criteria for Gnangara and Jandakot groundwater resources; and
- to review the ecological monitoring programs associated with management of the GDEs in the study area, recommending a revised program, which incorporates relevant parameters as identified in the first stage of this report, to provide information on the achievement or otherwise, of the finally determined management criteria.

Parameter Identification

Wetland vegetation

Overstorey species have many important ecological functions and tend to persist in highly disturbed plant communities, making them useful long-term indicators of environmental condition and health within wetlands. Emergent macrophytes are well suited as short-term indicators as they form dominant communities in wetlands, perform important ecological functions and are highly responsive to inter-annual variability in wetland surface levels. Invasive exotic species and annual exotic grasses are relatively quick to colonise disturbed areas and may be useful as short-term indicators of disturbance within wetland vegetation communities. Plant species can also be used to reflect water quality (i.e. eutrophic or saline conditions).

Parameters which can be used to measure the above indicators include:

- species diversity of wetland plant communities;
- cover and abundance of indicator plant species;
- species evenness over time;
- weediness index overtime;
- regeneration index over time;
- canopy fullness/density of indicator species;
- community distribution/zonation change or distribution of indicator plant species along a gradient;
- size (height) and age structure of a local population.

When monitoring wetland vegetation it is important to measure environmental variables that will influence vegetation communities, namely:

- groundwater levels and fluctuating water regimes (duration of wet/dry phases, seasonality etc);
- water quality (nutrient concentrations, salinity, toxicants);
- soil water retention capacity and soil stratigraphy (water retention layers);
• climatic information (rainfall and maximum temperatures during summer/early autumn);
• frequency of fire disturbance (measured by recording the presence or absence of fire ephemeral native legumes).

Macroinvertebrates, water quality and soils

Macroinvertebrates

Aquatic macroinvertebrate population and species assemblages are commonly used in routine wetland monitoring as indicators of change in water quality as they are influenced by colour, eutrophication, salinity and seasonality of a wetland. SWAMPS (Swan Wetlands Aquatic Macroinvertebrate Pollution Sensitivity) is a biotic index for wetlands in the Perth region, which reflects the sensitivities of aquatic macroinvertebrate taxa at the family and species level to anthropogenic disturbance, particularly nutrient enrichment. Family/species richness and abundance need to be measured in order to determine species assemblages and subsequent biotic indices.

The following characteristics of wetland soils and the water/sediment interface are likely to be useful as indicators of wetland health:

- physical conditions: groundwater levels; soil saturation; structural changes (i.e. soil erosion); soil type; soil temperature
- chemical conditions: redox potential; degree of oxygenation; pH; ferric/ferrous iron; CH4, CO2, H2S, sulphide and sulphate
- biotic conditions: fossils (diatoms); microbial communities; meiofaunal communities (biota <50um in size); macroinvertebrates.

Parameters measured at the water/sediment interface, to indicate the likely mobilisation of toxic materials in the water column include:

- pH, redox, DO, proportion of silt and clay, salinity and conductivity

Water quality

Measuring the following physicochemical parameters is a vital component of any assessment of wetland condition:

- pH
- dissolved oxygen (DO) and DO/temperature profiles
- biochemical oxygen demand (BOD)
- total organic carbon (TOC)
- hardness
- conductivity
- salinity
- nutrient concentrations such as nitrogen (N) and phosphorus (P)
- colour
- chlorophyll a measurements
Monthly conductivity and pH monitoring represents the most inexpensive and least labour intensive form of water quality monitoring.

**Phreatophytic terrestrial vegetation**

Abundance, character and condition of phreatophytic vegetation can be measured at seasonal intervals and used to interpret which aspects of the water regime are influencing the plant community.

- **Abundance**: distribution (reduction/expansion) of a community along a water availability gradient.
- **Character**: species diversity and composition; weed invasion; and structural changes (height and age structure).
- **Condition**: condition of plant vigour at the community level can be detected as a change in area, by shifts in community boundaries and by increases in opportunistic/invasive species or species more closely associated with wetter or drier conditions. Population vigour can be assessed using indices of canopy vigour; and regeneration potential (includes lack of regeneration, recruitment rate, seedling survivorship and seed bank viability).

Soil moisture is useful as an indicator of groundwater drawdown and its influence on phreatophytic vegetation, providing physical and biotic characteristics are allowed for and monitoring is frequent and continuous.

As fire can temporarily reduce the vigour of some plant species it is important to consider fire frequency and intensity when assessing the structure, condition and composition of native plant communities. It is also important to keep in mind the possibility of the presence of root fungi (*Phytophthora* species), which causes dieback in many native species, when assessing the vigour of plant species and communities.

**Threatened Ecological Communities: Cave stream communities and tumulus mound springs**

The parameters described for wetland monitoring can be applied to macroinvertebrate and water quality monitoring of cave streams and tumulus mound springs. In addition, groundwater levels in bores upstream of the caves should be monitored as an early warning of impending declines in flows.

The condition of the Tuart root mats in the caves, which provide habitat and food for the fauna, is similarly important. Photo points should be used to monitor the condition of selected root mats.

**Frogs, Reptiles, Landbirds, Mammals and Waterbirds**

**Frogs**

Recruitment of metamorphs (recently metamorphosed frogs) is the critical stage in the life cycle that is most affected by changed groundwater levels. This is best measured by sampling frogs and determining the population structure in the sample through measuring all specimens.

**Reptiles**

The distribution of reptiles across the landscape may alter through groundwater changes impacting upon vegetation and could be monitored by establishing transects
of pitfall and funnel traps radiating away from wetlands and crossing well into upland vegetation types.

**Landbirds and mammals**

Birds that visit an area each year to forage on nectar will decline in abundance or cease visiting when the nectar supply falls, resulting in a rapid response to groundwater changes.

Semi-aquatic mammals (e.g. Water-Rats) requiring permanent water could be monitored through trapping annually or at greater intervals. Among terrestrial native mammals, the Honey Possum may be of interest because of its dependence upon a year-round nectar supply, particularly from Banksias.

**Waterbirds**

Waterbirds are highly dependent upon wetlands with different species requiring different elements of the wetland environment. Monitoring has found waterbirds to be useful indicators in three ways:

- breeding by several species corresponds with high spring peak water levels;
- some wetlands provide open shallows and mudflats that are favoured for foraging by shorebirds and some ducks, and these habitats are vulnerable to invasion by phreatophytic vegetation if peak water levels are not achieved in at least some years;
- open, permanent or near-permanent water is important as a drought refuge for waterbirds.

Waterbird monitoring should target representative wetlands for their role in supporting breeding, shorebirds and in acting as drought refugia.

**Surface water and groundwater levels**

The monitoring of groundwater levels provides the best ‘early warning’ capability of the potential impacts of changing groundwater levels on ecosystem health as such measurements are a direct representation of groundwater levels. However, this parameter is only useful if we know how the ecosystem attributes and values respond to changes in groundwater levels. Ecosystem and species response curves against water availability are needed to enable the use of early warning of change in groundwater levels (and rainfall) to infer the risk of these changes to the ecosystem.

**Review of GDE monitoring on the Gnangara and Jandakot Mounds**

**Wetland vegetation monitoring**

Wetland vegetation monitoring is carried out at 19 wetlands on the Gnangara mound and 9 wetlands on the Jandakot mound. The objective of monitoring is to document any changes in fringing and emergent vegetation, and to determine if any observed changes are related to alterations of the groundwater regime or to other factors affecting the wetlands.

Monitoring is undertaken annually in spring. A range of parameters are measured at the permanent monitoring transects including: tree position; stem diameter at breast height (DBH); species richness; crown health; species cover and abundance; weediness index; and regeneration index.
**Macroinvertebrate, water quality and wetland soils monitoring**

Macroinvertebrate and water quality monitoring is carried out at 14 wetlands on the Gnangara mound and 9 wetlands on the Jandakot mound. The objective of monitoring is to describe the status of aquatic macroinvertebrates in terms of family richness and community structure, their response to changes in water quality and water levels and to provide an indication of whether groundwater abstraction schemes are having an impact on the identified ecological values of wetlands.

Macroinvertebrate (sweep netting) and water quality monitoring takes place late in winter/early spring and summer/early autumn, in three of the most dominant habitat types at each wetland. Environmental parameters measured *in-situ* include pH, conductivity, temperature, DO (mg/L and % saturation) and mean depth for each site. Chlorophyll-a, nitrate/nitrite, orthophosphate, total nitrogen, total phosphorus, colour (gilvin or soluble humic colour) and formazin turbidity (FTU) are all measured from water samples collected at each site.

**Phreatophytic terrestrial vegetation monitoring**

Phreatophytic vegetation monitoring is carried out at 17 locations on the Gnangara Mound and at 5 locations on the Jandakot mound. The objective of monitoring is to relate vegetation condition to soil moisture, climate and pumping operations.

Triennial monitoring takes place during spring. Tree species are recorded along with DBH, stem condition, the presence/absence of seedlings and the presence/absence, density and percentage foliage cover of understorey species.

**Current Threatened Ecological Communities monitoring**

**Cave stream communities**

Annual monitoring of the fauna and water quality is currently undertaken in seven caves on the SCP. The objective of monitoring is to provide an indication of whether groundwater abstraction and pine plantation management are having an impact on the identified ecological values of cave streams in Yanchep National Park.

Sampling is timed to take place when water levels are at their highest (mid-spring). DO, turbidity, salinity, conductivity, pH, redox and water temperature are recorded at each site. Water samples are also collected and calcium, potassium, magnesium, nitrate, nitrite, sodium, soluble reactive phosphorus and sulphate measured in the laboratory. Water levels within the caves are monitored monthly by Water and Rivers Commission.

**Tumulus Mound Springs**

Two seepages on the Gnangara mound are subject to monitoring, Egerton and Edgecombe Tumulus Springs. The objective of monitoring is to detect adverse changes in the ecology of the seepages, resulting from too rapid drawdown of the water table or increasing nutrient concentrations within the groundwater of the Gnangara mound.

Aquatic fauna samples are collected at the springs along with sediment and detritus. Water quality monitoring is also undertaken and sample analysed for ammonium, nitrate/nitrite, total nitrogen, orthophosphate, total phosphorus, total iron and sulphate.

**Frog, reptile, landbird, mammal and waterbird monitoring**

**Frogs**
Monitoring of frog populations is currently undertaken at two wetlands on the Gnangara mound, Lexia 86 and EPP Wetland 173 (frog, reptile, landbird and mammal monitoring does not occur on the Jandakot mound). The primary aim of the monitoring program is to determine if public groundwater abstraction is affecting frog populations within the study area.

Four monitoring methods are utilised as part of the monitoring regime: pitfall trapping; surveying calling males; tadpole surveying; and site descriptions.

**Waterbirds**

Waterbird monitoring has been conducted at 12 wetlands on the Jandakot mound since 1996 (waterbird monitoring does not occur at wetlands on the Gnangara mound). The aim of monitoring is to gather information on waterbird usage of wetlands that are influenced by the Jandakot mound, so that impacts of current or future groundwater abstraction can be assessed.

Waterbird monitoring is conducted during the autumn/winter and spring/summer periods. Waterbird activity (active/inactive/overhead) and habitat (shore/shallows/open water/fringing vegetation/overhead) are recorded in addition to total number counts.

**Current surface water and groundwater level monitoring**

The Water and Rivers Commission currently monitors approximately 1300 bores on the Gnangara and Jandakot mounds, collecting around 7100 water level readings annually. Monitoring is carried out either monthly or bi-annually, although the frequency can vary depending on bore location and the specific purpose of monitoring.

**Limitations and Knowledge Gaps**

It is imperative to adopt a holistic approach when assessing potential impacts on wetlands, given the spatial and temporal complexity many of these systems exhibit. As such, it is important to coordinate monitoring of the same GDE components carried out by different monitoring agencies/individuals across the study area, to ensure the same protocols are adhered to, objectives are met, standards are maintained and reliable information delivered.

**Wetland vegetation monitoring**

A number of areas of high ecological value and under threat from predicted drawdown are not included in current monitoring (listed in following Monitoring Recommendations section).

Groundwater monitoring bores at a number of wetlands at which wetland vegetation monitoring occurs, are not within close proximity (<100m) of the vegetation monitoring transects and are not likely to reflect the groundwater levels required by the wetland vegetation monitored along the transects (listed in following Monitoring Recommendations section).

More frequent monitoring may be required in circumstances of extreme drought.

**Macroinvertebrate and water quality monitoring**

None of the indicators currently used are set within the context of hypotheses. In order to be rigorous about developing an adaptive response capacity for monitoring,
monitoring programs should be underpinned by hypotheses which incorporate compliance criteria.

There are a number of critical areas where environmental values have been ascribed but where monitoring is not yet undertaken (listed in following Monitoring Recommendations section).

Water quality monitoring does not incorporate any analysis of biogeochemical indicators, a crucial issue given the emergence of acidification as a process relevant to the Swan Coastal Plain.

**Phreatophytic terrestrial vegetation**

It is difficult to determine existence of clearly defined objectives for monitoring of terrestrial vegetation on the Gnangara and Jandakot mounds. Monitoring programs should be underpinned by hypotheses which incorporate compliance criteria.

Groundwater levels are not recorded at monitoring transects, making comparisons between vegetation changes and hydrology difficult.

A number of areas of terrestrial vegetation of high conservation value, predicted to undergo further groundwater declines and not currently monitored (listed in following Recommendations section).

Soil moisture measurements have been inconsistently measured at transects and cannot be correctly interpreted without greater frequency of sampling.

**Threatened Ecological Communities: Cave stream communities and tumulus mound springs**

While the occurrences of tumulus springs and aquatic root mat communities on the Gnangara Mound are regularly monitored, occurrences of the following ten TECs are not monitored:

- Deeper sandy wetlands of sandy soils; Sedgelands in halocene dune swales of the southern SCP; Herb rich saline shrublands in claypans; Forest and woodlands of deep seasonal wetlands of the SCP; Perth to Gingin Ironstone Community; Herb rich shrublands in claypans; *Eucalyptus (Corymbia) calophylla* – *Xanthorrhoea preissii* woodlands and shrublands, SCP; Shrublands on calcareous silts of the SCP; *Banksia attenuata* woodland over species rich dense shrubland; and Shrublands on dry clay flats.

Current hydrological conditions of 16 caves on the SCP are unknown as they have not been entered in the last 10 years (listed in following Monitoring Recommendations section).

A number of springs upstream of the proposed Lexia wellfield, containing restricted and endemic invertebrate fauna, were not selected for monitoring/conservation/setting EWRs as they fell outside a previously defined study area. These sites all now lie within the greater study area and should be included in current monitoring.

Although water quality and macroinvertebrate monitoring is undertaken at Egerton Spring, phreatophytic vegetation remains unmonitored.
**Frogs, reptiles, landbirds and mammals and waterbirds**

**Frogs**

The timing of frog trapping during 2003 was such that winter breeding species were past their breeding peak and as a result numbers of these species have probably been under-estimated.

**Waterbirds**

Total waterbird species counts are not possible where dense wetland vegetation restricts access and visibility and are also not possible for cryptic species such as some crakes and rails, the Clamorous Reed-Warbler and the Little Grassbird.

**Surface water and groundwater levels**

A high percentage of monitored wetlands on the Gnangara and Jandakot Mounds have been found to have either no criteria bores, inappropriately located bores or to have provided no/insufficient groundwater and/or surface water data (listed in following Monitoring Recommendations section).

A number of wetlands have groundwater monitoring bores which are not within close proximity (<100m) of vegetation monitoring transects (and are not likely to be reflective of the groundwater levels required by the wetland vegetation) (listed in following Monitoring Recommendations section).

Discrepancies between data obtained from monitoring bores and wetland water levels have been identified at Melaleuca Park EPP 173.

Groundwater monitoring at Bibra Lake has not occurred since 1999, despite being entirely groundwater dependent and having habitat diversity and waterbird refuge values.

**Monitoring Recommendations**

A protocol has been developed for the monitoring of Australian wetlands, involving a logical series of steps with feedback loops to encourage adaptive management. The steps are as follows:

- Objectives → Management expectations → Assumptions → Gaps in knowledge or uncertainties → Performance criteria → Feasibility and cost effectiveness → Sampling methods → Analysis of samples → Reporting of results → Critical review.

**System level recommendations**

The current program lacks clear identification and definition of monitoring objectives and assessment criteria at the higher system or overarching level. The following system level objectives for the monitoring of GDEs on the Gnangara and Jandakot mounds:

1. to forecast system level response to a changing groundwater/surface water regime (there is currently no forecasting built into the monitoring program);
2. to ensure an early-warning system for critical GDE components; and
3. to improve understating of GDE response to a changing groundwater/surface water regime.
Suggestions for system level criteria that may be used to forecast a changing groundwater/surface water regime include:

- rainfall falling below the long-term average;
- proportion of surface water on the SCP (excluding areas of perched surface water) falling below the long-term average;
- proportion of rechargeable rainfall (taking into account the proportion of land on which recharge can occur and the rate of recharge) falling below the long-term average.

In order to address the second and third objectives,

Specific criticisms have also been made with regards to the lack of clearly identifiable objectives within the wetland vegetation, macroinvertebrate and water quality and phreatophytic vegetation monitoring programs. It is recommended that for each GDE component and relevant monitoring program, clear identification and definition of monitoring objectives be developed and expressed as testable hypotheses. These hypotheses should incorporate compliance criteria, which are in turn related to the groundwater regime.

The following rationale is recommended as a guide for the selection of monitoring sites within each GDE component:

- all GDE classes are included and well represented;
- areas of high conservation and under high risk are included;
- sites at which existing monitoring occurs but at which values have been lost are removed; and
- monitoring data from each site collectively contribute to the understanding of GDE response to changing groundwater/surface water regimes.

**Wetland vegetation monitoring**

Recommended changes and additions to the existing wetland vegetation monitoring programs on the Gnangara and Jandakot mounds include the clear identification and definition of monitoring objectives, incorporating compliance criteria and expressed as testable hypotheses.

Expansion of current vegetation monitoring to include the following wetlands at which high conservation values have been identified and/or are at greatest risk of impact from drawdown:

- Loch McNess; Central Yeal – wetlands 161, 188, 221, 276; Yeal Swamp – Lake Bindiar, Yeal Swamp and wetlands 137, 181, 193; North-east Yeal – wetlands 231, 234, 235; Lake Pinjar; Lake Gwelup; Big Carine Swamp; Lake Muckenburra; Bambun Lake; Kings Spring; Quin Brook; Lake Forrestdale; Mather Reserve; Spectacles North; and Harrisdale Swamp.

Groundwater monitoring bores need to be re-located at the following wetlands to ensure they are within close proximity (<100m) of wetland vegetation monitoring transects:

- Lake Yonderup; Lake Joondalup; Lake Jandabup; Dampland 78; Thomsons Lake; North Lake; and Lake Kogolup North.
Criteria indicative of periods of extreme drought, which if breached trigger more frequent (i.e. monthly) monitoring of wetland vegetation, need to be set (e.g. winter rainfall falling below the long-term average).

Comprehensive examination of ecological processes that maintain fringing wetland vegetation is required.

**Macroinvertebrate and water quality monitoring**

Recommended changes and additions to the existing macroinvertebrate and water quality monitoring programs on the Gnangara and Jandakot mounds include the clear identification and definition of monitoring objectives, incorporating compliance criteria and expressed as testable hypotheses.

The following wetlands have significant macroinvertebrate values and are valuable additions to the monitoring program:

- Yeal Swamp, Central Yeal and North-east Yeal; Swamp systems south of Gingin Brook; Perth Airport Swamps; and Twin Swamps.
- Coogee Springs and Lake Wilgarup could be removed from the monitoring program if previous environmental values are not re-established.

Consider adding a benthic invertebrate sampling program, particularly for the indicator group Oligochaeta, to invertebrate monitoring protocols.

Identify invertebrates previously sampled to the lowest taxonomic level in order to determine the presence of rare taxa which may be threatened by continued declines of water level and quality at the following high priority wetlands where habitat loss is evident:

- Lake Mariginiup; Nowergup Lake; Melaleuca Park EPP 173; Lake Wilgarup; Coogee Spring; Lexia 86; and Lexia 186.

Consider introducing the analysis of sulphate and total iron (as early warning measures of acidification onset) and calcium (as a measure of buffering capacity) to water quality analysis for each wetland.

Frequency of monitoring sampling should be sufficient to cover seasonal variation. Sampling should ideally be at intervals of two months or less (ensuring sampling occurs at least twice per year) and that ‘first flush’ of water into wetlands at start of winter rains must be sampled to provide valuable information on nutrient loading into wetlands.

**Phreatophytic vegetation monitoring**

Recommended changes and additions to the existing phreatophytic terrestrial vegetation monitoring program on the Gnangara and Jandakot mounds include the clear identification and definition of monitoring objectives, incorporating compliance criteria and expressed as testable hypotheses.

Current monitoring should be expanded to include the following areas of high priority terrestrial vegetation:

- Central Yeal; PM4 (Muchea); and North Muchea.

Hydrological monitoring at existing and additional sites should include at least one monitoring bore near the mid-point of monitoring transects. Monitoring of transects should occur at regular, three year periods. Monitoring bores located within close...
proximity to stands of native phreatophytic vegetation should be constantly checked for compliance with pre-determined environmental water provisions (EWPs), particularly during years of poor recharge. If monitoring indicates water levels are likely to breach pre-determined EWPs, the frequency of groundwater monitoring needs to be increased or in a worst case scenario, pumping from local production wells should cease until sufficient groundwater recharge occurs.

Further investigation of the effects of different fire regimes on species and communities and review of fire regimes at monitoring sites should be undertaken.

Further research is required to determine the groundwater drawdown tolerance thresholds of the drought sensitive Holly-leaf Banksia (*Banksia ilicifolia*) at various depths to groundwater, in order to further understand the significance and potential impacts of declining groundwater levels on this species. Further research is also needed to determine if the presence of the root fungi *Phytopthora* may be contributing to the decline of *Banksia attenuata* at Whiteman Park, Yanchep and Yeal transects.

**Threatened Ecological Community Monitoring**

The following ten, currently unmonitored, groundwater dependent TECs identified on the SCP, should be included within future monitoring of TECs:

- Deeper sandy wetlands of sandy soils: occur within Central Yeal sub-area (wetland 195-MILT05) and Ridges sub-area (wetland 444-YAN21).
- Sedgelands in halocene dune swales of the southern SCP: occur within Wanneroo Linear Wetlands west of Lake Wilgarup and north of Pipidinny Swamp (XYAN10).
- Herb rich saline shrublands in claypans: occur in a number of locations including sites around sites around Lake Bambun (GINGIN 01, 02, 03; BAMBUN 01, 03), Bullsbrook (BULL 06, BULL 08) and to the north of the study area at Lake Muckenburra (MUCK 02).
- Forest and woodlands of deep seasonal wetlands of the SCP: occur at Lake Bambun (BAMBUN 02) north of Yeal Nature Reserve and north-east of Lexia (TWIN05, TWIN10).
- Perth to Gingin Ironstone Community: this critically endangered TEC occurs on land adjacent to the Gingin airfield (NIRONSE, NIRONSE2, NIRONSW, NIRONNW, NIRON02, NIRON03).
- Herb rich shrublands in claypans: Five occurrences of this vulnerable TEC occur east of Bullsbrook (ELLEN 01, ELLEN 02, ELLEN 03, ELLEN 04, ELLEN 05).
- *Eucalyptus* (*Corymbia*) *calophylla* – *Xanthorrhoea preissii* woodlands and shrublands, SCP: occur east of Bullsbrook (PEARCE 02) and in Ellenbrook (ELLEN 06).
- Shrublands on calcareous silts of the SCP: this vulnerable community type is founding the Ellenbrook area east of Lexia (VINESSE).
- *Banksia attenuata* woodland over species rich dense shrubland: occur within the Gnangara Road Bushland (Telstra01-08), Decoursey Road Bushland (GOLF01-03), Landsdale Road Bushland (LAND01), Errina Road Bushland (ERRINA01-05).
• Shrublands on dry clay flats: occurrences of this endangered TEC occur include Forrestdale Lake and adjacent bushland, Anstey/Keane dampland and adjacent bushland and Nicholson Road bushland.

Cave stream communities

A detailed survey of the whole Gnangara mound should be conducted as soon as possible to determine the presence of endemic stygofauna and establish taxonomic relationships to known stygofauna and cavernicole fauna of the area/region. Methodology should be based on recommendations by the EPA for stygofauna monitoring.

The following 16 caves should be revisited as soon as possible to determine their current hydrological regime:

• Cave YN59; Cave YN86; Cave YN110; Cave YN151; Cave YN197; Cave YN203; Keyhole Cave (YN217); Cave YN233; Cave YN254; Cave YN289; Cave YN298; Cave YN362; Cave YN371; Cave YN397; Goalpost Cave (YN403); and Cave YN465 (although this cave may not be accessible).

Monitoring of cave stream fauna should take place in September/October, when habitat area is likely to be greatest.

Boomerang Cave should be included in future monitoring to determine if the TEC has been lost at this site since drying out as a result of maintenance issues with the recharge system.

Photo points should be used to monitor the condition of selected root mats in caves, specifically the areal coverage of root mats and the presence of active new growth, as they provide important habitat and food for cave fauna.

Tumulus mound springs

It is recommended the current status of the following sites (located within the Ellenbrook area on the Gnangara mound – see Jasinska and Knott (1994) for location details of numbered sites), currently unmonitored as they were located outside earlier study areas, be determined as soon as possible and any sites found to contain extant fauna be included in routine annual monitoring:

• Site 3 swamp (3s), Bullsbrook; Site 3 road (3r), Bullsbrook; Site 3 bush (3b), Bullsbrook; Site 4 nursery (4), Bullsbrook; Site 5 spring (5s), Muchea; Site 5 dam (5D), Muchea; Site 5 piezometer spring (5ps), Muchea; Site 5 piezometer dam (5pD), Muchea; Site 7 runnel (7), Bullsbrook; and Kings Spring.

Monitoring of the aquatic fauna at Egerton Spring should include specific searches for gilgies, as they were not recorded during 2002 surveys despite the probability they still exist on the spring mound.

The preparation of a ‘user friendly’ voucher and identification key of the taxonomic traits of each species occurring on Egerton Spring is recommended as a high priority.

In October 2002 it was proposed to install a small weir on Egerton Spring in order to measure runnel discharge, although to date this has not been installed. It is recommended runnel discharge be monitored monthly from October through to the commencement of rains the following year to enable rapid response should discharge rates drop substantially.
Continued monitoring of Edgecombe Spring is recommended for at least two more years to determine whether or not there is a substantial return of fauna, after which the usefulness of this monitoring program should be assessed.

Kings Spring, a tumulus mound spring located northwest of Bullsbrook, should be included in current monitoring as it supports a TEC.

Frog, reptile, landbird, mammal and waterbird monitoring

Frogs

Tadpole trapping should be used to monitor recruitment of larvae into wetland populations. Tadpole trap calibrations should be undertaken at Lexia 86 during 2004 to increase sample sizes available for analysis and should be carried out slightly later in the year (November) than was possible in 2003 to detect species that breed late in spring.

Pitfall trapping should be used to detect breeding success of adult frogs (particularly *H. eyrie*) and recruitment success as measured by captures of metamorphs.

Censuses of calling males to enable comparisons of densities between years could be repeated more often and preferably in a few months such as July and November, to allow greater resolution for examining fluctuations in populations and seasonal effects.

Waterbirds

Waterbird monitoring should target representative wetlands for their role in supporting breeding, shorebirds and in acting as drought refugia, such as:

- Loch McNess; Lake Yonderup; Pipidinny Swamp; Coogee Springs; Lake Nowergup; Lake Joondalup; Lake Goollelal; Lake Jandabup; Lake Marigininup; Lexia 94; EPP Wetland 173; Melaleuca Park Wetlands; Edgecombe Seepage; Lake Yakine; Thomsons Lake; North Lake; Bibra Lake; Yangebup Lake; Kogolup Lake; Twin Bartram Swamp; Beenyup Rd Swamp; and Forrestdale Lake.

The current uncertainty as to whether or not waterbird monitoring on the Jandakot mound will be continued during 2004. Uncertainties of this nature should be resolved as soon as possible so that seasonal sampling periods are not restricted.

Surface water and groundwater monitoring

Poor correlations exist between groundwater and surface water levels and groundwater gradients into and/or out of the wetlands area at the following wetlands and alternative monitoring bores may be required:

- Lake Yonderup; Lake Joondalup; Lake Nowergup; Lake Thomson; Forrestdale Lake; and Bibra Lake.

Poor correlations exist between groundwater and surface water levels and evidence of perched water tables at the following wetlands and alternative monitoring bores may be required:

- Coogee Spring; Melaleuca Park EPP 173; Shirley Balla Swamp; Lake Thomson; North Lake.
Moderate correlations exist between groundwater and surface water levels and groundwater levels are declining more rapidly than wetland levels at the following wetlands and alternative monitoring bores may be required:

- Lake Nowergup; and Lake Jandabup.

In addition, surface water data is required at the following wetlands before the relationship between groundwater and the wetland environment can be determined:

- Lexia 94; Lexia 186; Melaleuca Park Dampland 78; Pipidinny Swamp; Egerton Seepage; Edgecombe Seepage; Kogolup Lake South; and Bibra Lake.

The staff gauge at Pipidinny Swamp should be relocated to the large pond on southern side of access track as this pond is sampled annually as part of macroinvertebrate sampling and appears less artificial, while ongoing water level monitoring and actual depth measurements are required to determine seasonality of Pipidinny Swamp.

For new candidate sites or existing bores added to the network it is recommended that monthly water-levels are collected for a period of three years to characterise the aquifer response at each site. If water-levels vary little in magnitude, monitoring may be decreased to semi-annually or bi-annually. If there is irregular fluctuations or uncertainty in water-level behaviour, which cannot be attributed to a known event or land use change, more frequent monitoring may be required. Following the three-year period of monthly monitoring, assessment of the required monitoring at those new sites should be conducted. A review of sites currently monitored annually should be conducted to determine the best bi-annual sampling regime to capture both maximum and minimum trends.

Development of ecosystem and species response curves against water availability is required to enable the use of early warning of change in groundwater levels (and rainfall) to infer the risk of these changes to the ecosystem.
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1.0 INTRODUCTION

1.1 Objectives

The main objectives of this report are firstly, to propose environmental and biological condition indicators that reflect environmental values and have a defined relationship with groundwater levels and could be used together with water criteria within a management framework, as management criteria for Gnangara and Jandakot groundwater resources. This involves identifying parameters that can be used to directly reflect the ecological values, environmental condition and health of groundwater dependent ecosystems (GDEs), in contrast to the current approach that considers groundwater and surface water levels only.

The second objective of this report is to review the ecological monitoring programs associated with management of the GDEs in the study area, and recommend a revised program, incorporating relevant parameters as identified in the first stage of this report, to provide information on the achievement or otherwise, of the finally determined management criteria.

These objectives relate to Tasks 3 and 5, as outlined in the Study of Ecological Water Requirements on the Gnangara and Jandakot Mounds under Section 46 of the Environmental Protection Act Scoping Report (Froend and Loomes 2003b).

1.2 Methodological approach and report structure

With regards to the first objective, suitable monitoring parameters, reflecting the ecological values, environmental condition and health of GDEs, were identified by the project team. Literature addressing the collection of data for the purpose of GDE monitoring was also sourced. Suggested parameters were then considered in relation to a number of set criteria (as outlined in Froend and Loomes 2003b/described in Section 2), the results of which are presented in Section 2.

In order to meet the second objective, a desk-based review was undertaken of the most recently available reports documenting the monitoring programs for the following GDE components within the study area: wetland vegetation; macroinvertebrates, water quality and soils; phreatophytic terrestrial vegetation; Threatened Ecological Communities; frogs, reptiles, birds and mammals; and surface water and groundwater levels. The objectives of each monitoring program are presented in Section 3 along with outlines of the monitoring regimes (including monitoring locations, frequency of monitoring and the parameters measured).

Literature detailing protocols for the monitoring of Australia GDE components and reviews of the past and present GDE monitoring programs within the study area (where available), were also considered. The expertise of the project team was drawn upon to critique the existing monitoring programs in light of the relevant literature and the parameters previously identified (see Section 2) as the most suitably reflective of ecological values, environmental condition and health of GDEs. Limitations and knowledge gaps in the existing monitoring program were identified as part of this critique and are presented in Section 4.

Recommendations for a revised program were subsequently developed in response to these limitations, as well as to the recommended protocols for the monitoring of Australian GDE components (as identified in Section 2). The recommendations of the project team are presented in Section 5.
2.0 PARAMETER IDENTIFICATION

The identification of parameters that can be used to reflect the ecological values, environmental condition and health of GDEs need to meet a number of criteria, namely that they:

- **consider the ‘lag’ effects between depressed groundwater levels and environmental condition and/or health**: response of parameters influenced by depressed groundwater levels can take a long time and further reductions may be permitted before the impacts of previous changes are realised. As such, rapid response type parameters are favoured, as they provide advanced warning of significant stress or degradation on the system in question as well as providing the opportunity to determine whether intervention or further investigation is required (van Dam *et al.* 1999). However, some GDE values may have to be measured through parameters with a greater ‘lag’ effect (e.g. phreatophytic vegetation community composition);

- **have a defined relationship with groundwater levels**: there needs to be confidence that a measured response within a parameter reflects depressed groundwater levels rather than other influencing factors, such as long-term climatic variability, extended wet or dry periods, temperature effects and/or a myriad of other abiotic/biotic factors;

- **characterise risk to the environment**: parameters should identify, where possible, whether impacts to environmental values are short term or long term, reversible or irreversible and/or minor or major;

- **are cost-effective and practical**: parameters should be inexpensive enough to measure, although current monitoring practices may need to change to accommodate more appropriate additional or replacement parameters. Parameters that reflect landscape responses by GDEs of wide distribution, such as remote sensing of phreatophytic vegetation health, will be considered in light of the cost-effectiveness of such approaches; and

- **have early warning capabilities**: the time from which a parameter indicates there is a potential change within a value, to the time that actual change occurs (lead-time), should be sufficient to provide the opportunity to implement appropriate management response (similar to the ‘lag’ effect of a parameter). Generally, the better the warning (the longer the period between potential change and actual change) the lower the accuracy of the parameter in portraying a response specific to a given stressor (i.e. depressed groundwater levels). A balance between these characteristics (lead-time and accuracy), should be considered to provide the most appropriate and cost-effective parameters. Further characteristics of early warning indicators and considerations which need to be taken into account when deciding on environmental, physical and/or chemical indicators are detailed in van Dam (1999).

The ability to make predictions of the impact of a modified water regime on ecosystem components depends on an understanding of the relationship between the ecosystem component (e.g. wetland vegetation, phreatophytic vegetation, macroinvertebrates etc) and the water regime (Froend and Zencich 2002). Consideration needs to be made of this relationship at all ecological levels community, population and individual, as all are invariably linked: an individual species response has implications for population response which in turn influences
community composition or structure (Froend and Zencich 2002). Parameters that reflect condition and health of ecosystem components can be applied to all levels. The following sections describe parameters which may be incorporated into existing monitoring programs.

2.1 Wetland vegetation

Community level parameters: Vegetation composition and structure

It is long now accepted that wetland water needs are reflected by the requirements of wetland vegetation as it provides numerous functions integral to the continued health of wetlands and the organisms they support (Loomes and Froend 2001b). Loomes and Froend (2001b) explain distribution, growth and reproduction of wetland vegetation have strong relationships to depth, duration and amplitude of seasonal flooding, demonstrated by measuring the response of wetland vegetation to altered water regimes. As each species is adapted to specific water level ranges, changes may cause a shift in community composition and structure: lowering water tables can result in a loss of species intolerant of drying and their gradual replacement by terrestrial species. Detailed knowledge of the relationships between plant community composition and water regimes is still lacking (Loomes and Froend 2001b; Loomes and Froend 2001c), although a handful of studies have sought to address this issue (see Froend et al. 1993; Groom et al. 2000; Loomes 2000). Loomes (2000) described the hydrology of 19 Swan Coastal Plain (SCP) wetlands in relation to the influence on composition and structure of wetland vegetation and grouped wetland vegetation species into hydrotypes, based on the water regimes they experienced, to predict the impact of altered hydrology on wetland vegetation composition and structure.

Overstorey species, where present, are generally used to define vegetation communities within wetlands and have many important ecological functions, making them suitable indicator species for monitoring wetland health (Pettit 1997). Overstorey species also tend to persist in highly disturbed plant communities when most other natives disappear (Pettit 1997), implying a greater lag response to changes in groundwater levels. As such, overstorey species are useful as long-term indicators of environmental condition and health.

Similarly, emergent macrophytes form dominant communities in wetlands and perform important ecological functions, also making them suitable indicators for monitoring wetland health (Pettit 1997). Emergent macrophytes are highly responsive to inter-annual variability in wetland surface levels and as such are well suited as short-term indicators, given their sensitivity to the early stages of a stressor (i.e. depressed groundwater levels).

Invasive exotic species such as Typha orientalis and annual exotic grasses can be measured as an indication of the level of disturbance within a wetland (Pettit 1997). This is important as high levels of weed invasion can have negative effects on species diversity and recruitment of native species (Pettit 1997). High levels of weed invasion within wetland vegetation are reflective of changes to community structure which in turn, may be a result of changes within the groundwater regime. As weed species are relatively quick to colonise disturbed areas, they may be useful as a short-term indicator of disturbance within wetland vegetation communities.
Frequency of fire disturbance can be measured by recording the presence or absence of fire ephemeral native legumes such as Acacia saligna, A. pulchella, and Jacksonia aternbergiana (Pettit 1997). Whilst fire frequency may not be directly related to depressed groundwater levels, it is an important consideration when evaluating parameters which reflect the health of GDEs as it can have a strong impact on the composition of wetland vegetation and can confound effects of other environmental factors, such as water regime, on the vegetation (McComb 1987).

Parameters with which the above indicators can be measured include:

- species diversity of wetland plant communities;
- species cover and abundance of indicator plant species;
- species evenness over time (using the Shannon-Weiner index (see Kent and Coker 1992));
- weediness index overtime (calculated as the transformed cover of exotic species divided by the transformed cover of native species to give an indication of the importance of the extent of weed invasion within a plot (see Ladd 1996));
- regeneration index over time (divide number of seedlings in the plot by the number of trees plus one, in the plot (see Ladd 1996), to give an indication of the health of wetland vegetation);
- canopy fullness/density of indicator species (e.g. overstorey species) to give an indication of the health of wetland vegetation (using the Crown Assessment Procedure as outlined in Ladd (1996));
- community distribution/zonation change along a gradient (to give indication of groundwater availability gradient as specific species are associated with specific depth to groundwater ranges (see Loomes 2000)).

**Population level parameters: Indicator species**

The population dynamics of appropriate indicator species can be used to reflect the health and condition of wetland vegetation. A number of wetland plants can be used as indicator species, in particular, dominant overstorey species (Pettit 1997). Overstorey species have many important ecological functions within wetland communities and as such are suitable indicators for monitoring wetland health (Pettit 1997). Given the relatively long ‘lag’ response of overstorey species to changes in groundwater levels, they are useful indicators of environmental condition and health over the long-term. Major overstorey species on the SCP include Eucalyptus rudis, Melaleuca rhaphiophylla, M. priessiana and Banksia littoralis (Froend et al. 1993).

Emergent macrophytes are also useful indicators of wetland health as they too form dominant communities in wetlands and perform important ecological functions (Pettit 1997). The comparatively rapid response of emergent macrophytes to inter-annual variability in wetland surface levels makes them well suited as short-term indicators of changes to wetland vegetation condition. Froend et al. (1993) describe the response of emergent macrophyte communities to altered water regimes, focusing on a number of key species: Baumea articulata, Baumea juncea, Typha orientalis, Schoenoplectus validus and Melaleuca preissiana. These species can be used as indicators of the condition of wetland vegetation.
Plant species can also be used to reflect water quality (i.e. eutrophic or saline conditions) (Pettit 1997). Species useful as indicators of saline conditions include: *Frankenia sp, Halosarcia haloinenoides* and *Melaleuca thyoides* (see Halse *et al.* 1993). Species which only occur in freshwater conditions include: *Melaleuca priessiana, Leptocarpus scariosus* and *Astartea sp* (see Halse *et al.* 1993).

Indicator parameters for wetland plants include:

- cover and abundance of indicator plant species;
- evenness of indicator plant species over time (using the Sorensons index of similarity in population attributes over time);
- regeneration index of indicator plant species over time (divide number of seedlings in the plot by the number of trees plus one, in the plot (see Ladd 1996));
- canopy fullness/density, presence/absence of dead branches and epicormic growth of indicator species can be measured to give an indication of the phenology or productivity (growth) of wetland vegetation (using the Crown Assessment Procedure as outlined in Ladd (1996)). Such features are important in understanding the vegetation dynamics of a community, so that effects of changes can be predicted (Pettit 1997);
- distribution of indicator plant species along a gradient (to give indication of groundwater availability gradient as specific species are associated with specific depth to groundwater ranges (see Loomes 2000)).
- size (height) and age structure of a local population can be measured to give an indication of drawdown effects. Populations affected by drawdown may demonstrate a lack of recruitment as water availability is insufficient to support successful establishment, and are characterised by few, mature individuals and no new recruits. In contrast, dynamic, resilient populations are characterised by many cohorts of different ages, particularly young individuals (Froend and Zencich 2002).

**Environmental variables**

When monitoring wetland vegetation it is important to measure environmental variables that will influence vegetation communities, while which environmental variables to measure will in part depend on the objectives of the monitoring program (Pettit 1997). Variables relevant to the objectives of existing wetland vegetation monitoring programs include:

- groundwater levels and fluctuating water regimes (duration of wet/dry phases, seasonality etc);
- water quality (nutrient concentrations, salinity, toxicants);
- soil water retention capacity and soil stratigraphy (water retention layers);
- climatic information (rainfall and maximum temperatures during summer/early autumn) can be useful in determining the cause of changes to vegetation (see Arrowsmith 1992);
records of past fires (as this may have strong impact on composition of vegetation and can compound effects of other environmental factors, such as water regime, on wetland vegetation (see McComb 1987)).

2.2 Macroinvertebrates, water quality and soils

2.2.1 Macroinvertebrates and soils

Macroinvertebrates are well suited for use in biological monitoring programs as they sedentary in nature, have comparatively long life cycles, have varied responses to a range of stressors within the aquatic environment, are relatively easy to sample and are generally well described taxonomically (Trayler and Davis 1997). Aquatic macroinvertebrate communities are influenced by colour, eutrophication, salinity and seasonality of a wetland (Davis et al. 1993). Trayler and Davis (1997) provide an overview of biological monitoring procedures which utilise macroinvertebrate fauna as indicators of water quality in wetlands on the SCP.

Indicator species

Monitoring biochemical and physiological changes that occur in individual organisms can be used to provide an early warning of adverse changes in water quality (Johnson et al. 1993). Abnormalities in the morphology of individual organisms and deviations from normal behaviour may also be used to indicate environmental stress, however these parameters all require further research before they could be utilised as on-going monitoring tools (Trayler and Davis 1997).

Macroinvertebrate population and species assemblages are commonly used in routine wetland monitoring as indicators of change in water quality. Davis et al. (1993) identify a range of taxa which respond positively to eutrophication, namely: *Daphnia carinata*, *Micronecta robusta*, *Agraptocorixa hurtifrons*, *Polypedilum nubifer* and *Kiefferulus intertinctus*. However, Trayler and Davis (1997) note that these species tend to be quite abundant in SCP wetlands and are generally opportunistic, therefore not the most ideal bioindicators. However, monitoring protocols can be designed around these species so that their abundance over prescribed levels could indicate a change in water quality (Trayler and Davis 1997).

By far the greatest effort as far as invertebrate survey and monitoring is concerned, has been placed on littoral invertebrates. The other major ecological category, the benthic invertebrates, are likely to be only incidentally sampled using the procedure described above. Littoral invertebrate monitoring can only play a limited role where sediment issues are central to the monitoring purpose. For instance, values associated with organic soils, or ‘metaphyton’, or lacustrine sediments, and the impacts on these sediment types associated with drying, should be monitored with benthic invertebrates, not littoral invertebrates. Oligochaete worms are a diverse and useful indicator group for benthic conditions and where applicable should be incorporated into rapid assessment protocols. So far this group has not been targeted, and taxonomic resolution of this group has been poor making any reliable use of trends problematic. With appropriate standard benthic sampling and increased taxonomic resolution, the group will provide the monitoring programme with a biotic indicator for sedimentary processes.
Biotic indices

Biotic indices provide a score, based on macroinvertebrate assemblages collected from a particular site, to provide a value by which the pollution status of a wetland can be determined (Trayler and Davis 1997). Individual taxa are assigned scores depending on their tolerance or intolerance to a particular pollutant and individual scores summed to produce a wetland index. SWAMPS (Swan Wetlands Aquatic Macroinvertebrate Pollution Sensitivity) was developed as a biotic index for wetlands in the Perth region, to reflect the sensitivities of aquatic macroinvertebrate taxa at the family and species level, to anthropogenic disturbance, in particular nutrient enrichment (Chessman et al. 2002). SWAMPS also shows strong correlations with the condition of fringing vegetation, introduced fish and anthropogenic changes to the water regime (Chessman et al. 2002). Chessman et al. (2002) found species-level SWAMPS indices were more strongly related to physical and chemical measures of water quality than family-level indices, although the latter is adequate for rapid bioassessment when the small loss of precision is acceptable given cost and time savings in not having to key specimens to species level. Where more subtle distinctions are necessary, for instance in performance monitoring and to obtain early warnings of adverse trends, species-level indices may be more appropriate (Chessman et al. 2002). Alternatively, a hybrid approach may be considered where species level identification takes place for families with high interspecific variation in sensitivity to stressors (Chessman et al. 2002).

The following parameters need to be measured in order to determine species assemblages and subsequent biotic indices:

- family/species richness
- abundance

Environmental Parameters

Baseline data on parameters of wetland soil quality on the SCP is surprisingly lacking, given the importance of sediments in processing concentrations of nutrients and toxic materials within a wetland (Horwitz et al. 1997). Horwitz et al. (1997) present a selective review of information on monitoring the condition of wetland soils on the SCP, listing the following characteristics of wetland soils likely to be useful as indicators of wetland health:

- **physical conditions**: groundwater levels; soil saturation; soil erosion; soil type
- **chemical conditions**: redox potential; degree of oxygenation; pH; ferric/ferrous iron; CH4, CO2, H2S, sulphide and sulphate
- **biotic conditions**: fossils (diatoms); microbial communities; meiofaunal communities (biota <50um in size); macroinvertebrates

The key to identifying suitable indicators for monitoring wetland soils on the SCP is recognising which suite of characteristics best depicts the wetland conditions under investigation (Horwitz et al. 1997). Physical, chemical and biotic characteristics of wetland soils influence one another as well as wetland vegetation and ecological processes, for instance: soil hydraulic conductivity influences the degree of nutrient flow to plants, which provides an indication of the status of wetland vegetation health; long-term monitoring of redox potential, degree of saturation of wetland soils and plotting the amount of organic material in the soil may also provide indications of
vegetation health; soil saturation, redox potentials, pH and the presence or absence of oxygen all influence the behaviour of nitrogen and phosphorus, in turn influencing the health of wetland vegetation (Horwitz et al. 1997).

Although there are few sources of baseline data for toxic materials and of environmental criteria for contaminants in wetland soils on the SCP, the following parameters, measured at the water/sediment interface, could all give an indication of the likely mobilisation of toxic materials in the water column (see Horwitz et al. (1997) for details of the relationship between parameters and the mobilisation of toxic materials):

- pH, redox, DO, proportion of silt and clay, salinity and conductivity

Structural changes in wetland soils which indicate soil loss or damage include:

- exposure of roots where soil has been consumed around them; cracks in the soil which create aerobic conditions and further loss of organic matter; remnant pedestals of organic soil; burnt edges of shallow organic soils (especially on the upslope of the edge of a lake) (Horwitz et al. 1998).

Indicators of soil damage in wetlands on the SCP due to drainage activities need to be established by simply observing exposed and dried organic soils in the presence of drains (Horwitz et al. 1997).

Diatom assemblages taken from core samples can provide information on the former trophic state of an already degraded wetland (Horwitz et al. 1997).

Horwitz et al. (1997) recommend the following approach be taken when monitoring of wetland soils:

- wetland soils should be characterised as part of vegetation transects: soil can be sampled using hand-held corers and/or augers and stratigraphy established by measuring depths of different layers and within each layer particle size, bulk density and soil organic matter determined.
- core parameters of porewater and water and the sediment/water interface should be regularly monitored: soil temperature, DO, redox potential (most critical) and pH, salinity/conductivity measured.
- critical parameters should be monitored where toxic materials are concerned: baseline levels of toxic materials such as heavy metals (i.e. Pb, As, Cu, Zn, Cd) and pesticides (i.e. dieldrin and DDT) need to be established and key parameters (such as those above) elucidated and monitored.

2.2.2 Water quality

*Environmental variables*

Long-term monitoring of physicochemical parameters provides a record of the characteristics of a wetland over time, while unusual changes in any of the parameters provides an indication that wetland characteristics, and possibly water quality, are changing (van Dam et al. 1998). The majority of physicochemical parameters are simple, inexpensive and quick to measure and should be included in any wetland monitoring program (van Dam et al. 1998).

Measuring the following physicochemical parameters is a vital component of any assessment of wetland condition (van Dam et al. 1998):

- High-resolution monitoring of water levels, temperature, conductivity, pH, DO, redox potential, salinity, and nutrient concentrations.
- Monitoring of water quality parameters such as dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, and nitrogen and phosphorus concentrations.
- Monitoring of water hydraulic parameters such as flow rate, water velocity, and water depth.
- Monitoring of water quality parameters that are influenced by physical processes such as erosion, sedimentation, and nutrient runoff.

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- pH
- dissolved oxygen (DO)
- biochemical oxygen demand (BOD)
- total organic carbon (TOC)
- hardness
- conductivity
- salinity
- nutrient concentrations such as nitrogen (N) and phosphorus (P)

More intensive monitoring should also include (see Morgan and Davis 1997):
- colour
- DO/temperature profiles
- chlorophyll \( a \) measurements

The frequency of sampling should be sufficient to cover seasonal variation, ideally with intervals of no longer than two months between sampling periods in order to encompass climatic variation on the SCP (Morgan and Davis 1997). The ‘first flush’ of winter rains into wetlands should also be sampled in order to collect information on nutrient loading into wetlands (Morgan and Davis 1997).

Consideration must be given to spatial and temporal variability when assessing overall wetland water quality from a small number of discrete samples (ANZECC 1992). Location, frequency and timing of sampling also need to be considered in relation to the type of water body and the indicators being sampled (ANZECC 1992). For example, DO and pH can be change dramatically throughout the day as a result of algal photosynthesis and respiration (ANZECC 1992). Similarly, the location at which samples are taken can influence the concentration of indicators such as pH, DO and N (ANZECC 1992).

Morgan and Davis (1997) provide general water quality criteria for the protection of the integrity of SCP wetlands and suggest monthly conductivity and pH monitoring represents the most inexpensive and least labour intensive form of water quality monitoring:
- measuring conductivity indicates how fresh or saline a system is (freshwater < 1500 mg/L or 2475 uS/cm) and while monitoring water depth will give an indication as to whether or not a wetland dries over winter, monitoring conductivity will provide information on how concentrated a wetland becomes and for how long the effects of drying may influence physicochemical and biological processes (Morgan and Davis 1997).
- monitoring pH is a similarly quick and inexpensive approach to provide valuable knowledge about the characteristics of a wetland: low pH may be indicative of coloured wetlands, wetlands with low to moderate enrichment are likely to fall within circumneutral pH, while pH of greater than 9 is likely to be associated with highly enriched wetlands with algal blooms present (Morgan and Davis 1997).
Morgan and Davis (1997) also suggest that given the simplicity and low costs involved with monitoring conductivity and pH, community groups and school children could be involved in monitoring these parameters as a means of increasing community participation in wetland protection and management.

2.3 Phreatophytic terrestrial vegetation

Understanding the groundwater requirements of a plant community requires knowledge of community responses to short and long-term effects of groundwater fluctuation, groundwater abstraction and poor recharge events (Groom et al. 2000). Generally though, these responses are poorly understood (Froend and Zencich 2002). Regular monitoring of different plant communities along with the underlying hydrology is required before relationships between floristic structure and composition and groundwater regimes can be confidently described (Groom et al. 2000). Current monitoring suggests long-term reductions in populations of drought-intolerant species on the Gnangara mound may be attributed to reduced soil moisture levels (Groom et al. 2000). Although more research is required to define these relationships and to improve the basis for decision making with regard to predicting the potential impacts of water regime modification on vegetation, Froend and Zencich (2002) provide details on specific parameters to measure, from which vegetation response to a given water regime can be correlated/associated (Froend and Zencich 2002).

Community level parameters

Abundance (area), character (composition, floristic richness and structural diversity) and condition (collective vigour) of phreatophytic vegetation can be measured at a community level (Froend and Zencich 2002). These variables are not a direct measure of the response of phreatophytic vegetation to the water regime, but can be used to interpret which aspects of the water regime are influencing the plant community (Froend and Zencich 2002).

Abundance:

- distribution (reduction/expansion) of a community along a water availability gradient may change in response to altered groundwater regimes. Alteration in the dominant species composition can be used as an indicator of change in community distribution (Froend and Zencich 2002).

Character:

- species diversity and composition in a community may change as species more vulnerable to prolonged dry periods become locally extinct and in severe cases diversity may be significantly reduced and comprise only xerophytic species (Froend and Zencich 2002);
- weed invasion may increase upon the death of drought intolerant species (Froend and Zencich 2002);
- structural changes, namely height structure, may occur in a community as mature trees senesce as a result of altered groundwater regime (Froend and Zencich 2002).
Condition:

- condition of plant vigour at the community level can be detected as a change in area, by shifts in community boundaries and by increases in opportunistic species or species more closely associated with wetter or drier conditions. Therefore, a measure of community condition can be determined by the presence or absence or area of invasive species (Froend and Zencich 2002).

Community level parameters should be monitored in seasonal/long-term intervals (i.e. annually) (Froend and Zencich 2002).

**Population level parameters: Indicator species**

The population dynamics of appropriate indicator species can be used to reflect the health and condition of wetland vegetation. The drought sensitive Holly-leaf Banksia (*Banksia ilicifolia*), has been identified as an important indicator of long and short term changes in groundwater levels on the Gnangara mound and on other shallow aquifers on the Swan Coastal Plain, as groundwater drawdown has a documented negative impact of population size and vigour of this species (Groom *et al.* 2000). *B. ilicifolia* is useful as a key indicator species as it is an overstorey species, usually easy to record and identify, and generally used to define vegetation communities (Pettit 1997). However, Groom *et al.* (2000) call for further research to determine the groundwater drawdown tolerance thresholds of *B. ilicifolia* at various depths to groundwater in order to further understand the significance and potential impacts of declining groundwater levels on this species.

Population level parameters as described below can be used to provide an assessment of population size and vigour of *B. ilicifolia*.

Abundance, character and condition of species response to water regimes can also be measured at a population level to describe species response to water regime (Froend and Zencich 2002). Once again, these factors are not a direct measure of vegetation response to a water regime, but rather associated with specific components of the water regime i.e. depth to groundwater (Froend and Zencich 2002).

**Abundance:**

- size of a local population is a measure of species persistence and resilience. Recruitment potential can be determined by the size and distribution of mature individuals and is also affected by density (Froend and Zencich 2002). Higher density stands of a species require greater water availability;

- distribution of a population along a water availability gradient is reflective of the water requirements of a species and changes in water regime that exceed the tolerance limits of individuals may lead to a gradual change in species distribution (Froend and Zencich 2002). Distribution of indicator plant species along a gradient can be used to give an indication of the groundwater availability gradient as specific species are associated with specific depth to groundwater ranges (see Loomes 2000).

**Character:**

- size (height) and age structure of a local population can be measured to give an indication of drawdown effects. Populations affected by drawdown may demonstrate a lack of recruitment as water availability is insufficient to support successful establishment, and are characterised by few, mature individuals and
no new recruits. In contrast, dynamic, resilient populations are characterised by many cohorts of different ages, particularly young individuals (Froend and Zencich 2002). Froend and Zencich (2002) note an exception however, when mature plants succumb to drawdown events, leaving only younger members of the population, tolerant of the ‘new’ water regime;

- longevity (and therefore persistence) and resilience of a local population may be significantly impacted by groundwater drawdown that exceeds the tolerance limits of a species (population) (Froend and Zencich 2002).

Condition:

- population vigour, or the appearance of a species, can be assessed using indices of canopy vigour (e.g. canopy condition index (fullness/density, presence/absence of dead braches and epicormic growth), leaf area index (LAI), Crown Assessment procedure (see Ladd 1996)). Other population measures of vigour include incidence of juvenile, mature, reproductive and senescent individuals and flowering in a population (Froend and Zencich 2002);

- regeneration potential is also reflective of condition or vigour of a population. Lack of regeneration potential (lack of seedlings, no juveniles or saplings, only senescent trees present) represents a serious loss of vigour (Froend and Zencich 2002). However, to use regeneration potential as a measure of drawdown impact requires other factors such as grazing or fire management to be ruled out. Parameters used to measure regeneration potential include lack of regeneration, recruitment rate, seedling survivorship and seed bank viability (Froend and Zencich 2002). Ladd (1996) describes the regeneration index of indicator plant species over time: divide number of seedlings in the plot by the number of trees plus one, in the plot.

Parameters measured at population level are generally monitored at seasonal, lifespan or annual intervals (Froend and Groom 1999).

**Individual level parameters**

Individual plant response to water regimes can only be measured and quantified in terms of condition (Froend and Zencich 2002). As such, standard physiological techniques that directly reflect the vigour of a plant are used when measuring the condition of individuals (Froend and Zencich 2002). These include:

- measurement of plant water relations via pre-dawn water potentials and gas exchange. These parameters reflect plant response over time to water availability, although only provide an indication of potential water source use (Froend and Zencich 2002);

- measurement of water uptake via sap flow technique, estimating water flow through the sapwood of an individual plant. This provides information on the consumptive use and process of water uptake by a species and infers water requirements from response to water availability (Froend and Zencich 2002);

- measurement of water sources used via isotopic tracers. This process allows water sources accessed by plants to be identified and the contributions of potential water sources to be recognised. Understanding the primary source of water for species within a region where water can become limiting is critical for
estimating and modelling community-scale water balance (Froend and Zencich 2002).

The above parameters provide a more defined relationship between groundwater levels and the condition of phreatophytic vegetation than community and population level parameters, however they are quite labour intensive, timely and costly and as such have a greater lag time and do not have efficient early warning capabilities. As a result, they are not considered suitable for incorporation into the monitoring program for phreatophytic vegetation but rather a critical component of specific research endeavours, which look to define the water-use strategies of phreatophytic species.

**Environmental Parameters**

Soil moisture can vary significantly from site to site as well as temporally within a specific location. Rainfall, types of soils and plant communities, differences in local recharge and transpiration rates, differences in local land uses and differences in relation to proximity of water extraction bores are all determinants of soil moisture conditions (Mattiske 2001). Researchers have predicted that lowered soil moisture conditions will result in a shift in the native vegetation to the xeric end of the continuum (see Havel 1975; Aplin 1976). This prediction is supported by results to date from the Jandakot mound terrestrial vegetation monitoring program (Mattiske 2001). Although a number of conditions other than groundwater levels influence soil moisture, this parameter is useful as an indicator of groundwater drawdown and its influence on phreatophytic vegetation, providing physical and biotic characteristics are allowed for and monitoring is frequent and continuous. Soil moisture can however be costly to monitor owing to specialised equipment required (i.e. tensiometers).

Structure, condition and composition of native plant communities are strongly influenced by fire frequency and intensity (Mattiske 2001). Fire can temporarily reduce the vigour of some plant species and if these species are placed under further stress (such as reduced soil moisture) the plant may suffer in the short-term and possible long-term (Mattiske 2001).

A major consideration when assessing the vigour of plant species and communities is the presence of root fungi (*Phytophthora* species) which causes dieback in many native species dominant on the SCP (Mattiske 2001). It is important to keep in mind the possibility of the presence of this fungus when interpreting monitoring results as it can lead to pockets of dead and dying trees and understorey species (Mattiske 2001).

### 2.4 Threatened Ecological Communities

Cave stream communities and tumulus mound spring share similar characteristics and attributes as wetlands, with regards to macroinvertebrates and water quality. As such, the parameters described for wetland monitoring (see Sections 2.2.1 and 2.2.2) can be applied to macroinvertebrate and water quality monitoring of cave streams and tumulus mound springs.

#### 2.4.1 Cave Streams

Caves streams depend upon adequate groundwater levels to provide permanent flows. Groundwater levels in bores upstream of the caves should be monitored as an early warning of impending declines in flows. Since the fauna of these cave streams require permanent flows, it is critical they are not allowed to dry. Monitoring should be
sufficiently far upstream of the caves as to give enough early warning to allow management action to rectify falling levels before the springs are affected.

As detailed in Section 2.2.1, macroinvertebrates are well suited to biological monitoring and assemblage structure can be assessed to provide an indication of the water quality of cave streams.

In addition to fauna monitoring, the condition of the Tuart root mats in the caves, which provide habitat and food for the fauna is important. Photo points should be used to monitor the condition of selected root mats.

2.4.2 Tumulus Springs

All springs depend upon the upstream hydrostatic head of the aquifer to provide water pressure and therefore permanent flows. Hydrologists should be consulted to provide a method whereby this head can be monitored as an early warning of impending declines in flows. Since the fauna of these springs require permanent flows, it is critical they are not allowed to dry. Monitoring should be sufficiently far upstream of the springs as to give enough early warning to allow management action to rectify falling levels before the springs are affected.

Sweep sampling and hand collection of material at tumulus springs has proven successful in detailing changes in assemblage structure of macroinvertebrates. As detailed in Section 2.2.1, macroinvertebrates are well suited to biological monitoring and assemblage structure can be assessed to provide an indication of water quality at the springs.

2.5 Frogs, reptiles, landbirds, mammals and waterbirds

2.5.1 Frogs

The main short-term impact of changed groundwater levels is upon breeding success but, because the adults of most frogs species are long-lived, populations may persist for years, even decades, after breeding has ceased. Therefore, surveys of calling males will only detect the catastrophic phase of the impact. Recruitment of metamorphs (recently metamorphosed frogs) is the critical stage in the life cycle that is most affected by changed groundwater levels. This is best measured by:

- sampling frogs and determining the population structure in the sample through measuring all specimens.

2.5.2 Reptiles

There is only one aquatic reptile currently widespread in groundwater areas: the long-necked tortoise *Chelodina oblonga*. Exhaustive trapping would be required to determine its presence in a range of wetlands, and would have to be repeated at intervals of several years to determine if populations were persisting or dying out. Other reptiles are dependent upon phreatophytic vegetation or occur in upland areas where some components of the vegetation may be affected by changes in groundwater levels. At least theoretically, the distribution of reptiles across the landscape may alter through groundwater changes impacting upon vegetation. For example, the range of a reptile species around a wetland may contract if the groundwater declines. This sort of impact could be monitored by:
• establishing transects of pitfall and funnel traps radiating away from wetlands and crossing well into upland vegetation types. Sampling would establish the landscape-level distribution of the more abundant reptile species and monitoring would detect changes in this distribution.

Note that reptile populations may well persist despite changes in groundwater levels, with only very slow landscape-scale population movements.

2.5.3 Landbirds and mammals

The concept of landscape scale distributions along what is essentially a habitat catenary related to groundwater, described above for reptiles, can also be applied to landbirds and mammals.

With landbirds, the mobility of species, including some that are migratory, can complicate the issue, but can also result in rapid changes. For example, birds that visit an area each year to forage on nectar will decline in abundance or cease visiting when the nectar supply falls, resulting in a rapid response to groundwater changes.

There are very few extant native mammals in the groundwater areas close to Perth, but there is one semi-aquatic species (the Rakali or Water-Rat *Hydromys chrysogaster*) that could be monitored. This requires permanent water (although disperses to seasonal wetlands) and populations on wetlands could be monitored through trapping annually or at greater intervals. Among terrestrial native mammals, the Honey Possum *Tarsipes rostratus* may be of interest because of its dependence upon a year-round nectar supply, particularly from Banksias. This species would be recorded in landscape sampling for reptiles.

2.5.4 Waterbirds

Waterbirds present a special case because they are highly dependent upon wetlands, different species require different elements of the wetland environment and the mobility of birds means that they can respond rapidly to change. Unfortunately, this also means that their population in one region can be affected by population changes in another region, and attempts to monitor waterbirds are often frustrated by irruptions of large numbers due to successful breeding elsewhere. Despite this, monitoring has found waterbirds to be useful indicators in three ways:

• breeding by several species corresponds with high spring peak water levels, apparently because these high levels surround trees such as paperbarks and the waterbirds breed in these trees when they are surrounded by water.

• some wetlands provide open shallows and mudflats that are favoured for foraging by shorebirds and some ducks, and these habitats are vulnerable to invasion by phreatophytic vegetation if peak water levels are not achieved in at least some years.

• open, permanent or near-permanent water is important as a drought refuge for waterbirds, and there is some evidence that species requiring deep, permanent freshwater have declined in the Perth region in the last decade.

These three points suggest that waterbird monitoring should target representative wetlands for their role in supporting breeding, shorebirds and in acting as drought refugia.
2.6 Surface water and groundwater levels

Understanding the relationship between groundwater parameters and ecosystem health is critical to predicting and/or modelling the impacts of changing groundwater regimes. The monitoring of groundwater levels provides the best ‘early warning’ capability of the potential impacts of changing groundwater levels on ecosystem health as such measurements are a direct representation of groundwater levels. However, this parameter is only useful if we know how the ecosystem attributes and values respond to changes in groundwater levels. This aspect of research and monitoring is weak. Ecosystem and species response curves against water availability are needed to enable the use of early warning of change in groundwater levels (and rainfall) to infer the risk of these changes to the ecosystem.

Choosing representative groundwater monitoring bore sites that will accurately reflect water levels in wetlands can be difficult given the variety of factors (excluding rainfall and evapotranspiration) that affect wetland water levels and nearby groundwater levels (Rockwater 2003). Factors which may affect surface water levels include (see Rockwater 2003):

- perching of water on sediments deposited in wetlands, affecting persistence of wetland;
- stormwater drainage causing raised levels; and
- transfer of water between wetlands regulating surface water levels.

Factors which may affect the groundwater levels measured in monitoring bores include (see Rockwater 2003):

- locating bores in capture and release zones;
- depth of monitoring bores where there are vertical differences in heads in the vicinity of the wetland and depth of capture zone;
- aquifer anisotropy affecting groundwater inflow;
- water levels in karstic release zones;
- upward and downward flow from underlying Mesozoic sediments; and
- groundwater pumpage.

Wetlands on the SCP can be classified into a number of groupings depending on shared, or unique, hydrogeological characteristics (Rockwater 2003). For instance, bores located in capture zones may be affected by increasing heads with depth and aquifer anisotropy, while bores located in release zones may be affected by downward-decreasing heads or by their locations in karstic areas of the superficial aquifer (Rockwater 2003). Based on these characteristics and the factors outlined above which influence groundwater and surface water levels, Rockwater (2003) recommend suitable locations for monitoring bores to ensure measured groundwater levels are reflective of surface water levels, for wetlands which occur within different hydrogeological groupings:

- for wetlands on the Bassendean Dunes groundwater levels measured in bores located near the null points between capture and release zones are likely to most closely reflect surface water levels. It is also considered groundwater levels measured in monitoring bores open to a depth of 3m below the water table will
closely reflect surface water levels, as the effects of upward and downward-decreasing heads in the aquifer are reduced;

- for wetlands in the Spearwood Dunes groundwater monitoring bores should not be located in the release zone due to the karstic nature of the aquifer. Monitoring bores should be located along the eastern sides of wetlands with sandy shorelines and bores should be constructed at a maximum depth of 3m below the water table in order to minimise the effects of upward heads.

The relationships between the monitoring parameters described for each GDE component and the parameter criteria are outlined in Table 1.
Table 1: Relationship of monitoring parameters to parameter criteria.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>‘Lag’ effect between depressed groundwater levels and environmental condition and/or health</th>
<th>Relationship with groundwater levels</th>
<th>Risk to the environment characterised</th>
<th>Cost-effectiveness and practicality</th>
<th>Early warning capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>WETLAND VEGETATION</td>
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<tr>
<td>Community level parameters</td>
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</tr>
<tr>
<td>species diversity</td>
<td>relatively long to very long</td>
<td>partly related to strongly related</td>
<td>long-term, reversible, minor to major impact</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>species cover and abundance</td>
<td>relatively long to very long</td>
<td>partly related to strongly related</td>
<td>long-term, reversible, minor to major impact</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>species evenness</td>
<td>relatively long to very long</td>
<td>partly related</td>
<td>long-term, reversible, minor to major impact</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>weediness index</td>
<td>relatively short to relatively long</td>
<td>partly related</td>
<td>short-term to long-term, reversible*, major impact</td>
<td>high</td>
<td>low</td>
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<tr>
<td>regeneration index</td>
<td>relatively short to relatively long</td>
<td>partly related</td>
<td>short-term to long-term, reversible*, major impact</td>
<td>high</td>
<td>low to high</td>
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<td>partly related</td>
<td>long-term, reversible, minor to major impact</td>
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<td>low</td>
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<td>canopy fullness</td>
<td>relatively short to relatively long</td>
<td>partly related</td>
<td>long-term, reversible, major impact</td>
<td>high</td>
<td>low</td>
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<tr>
<td>community distribution/zonation change</td>
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<td>partly related to strongly related</td>
<td>short-term to long-term, reversible*, major impact</td>
<td>high</td>
<td>low to high</td>
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<tr>
<td>Population level parameters</td>
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<tr>
<td>cover and abundance of indicator species</td>
<td>annual species: very short to relatively short perennial/tree species: relatively long to very long</td>
<td>strongly related</td>
<td>annual species: short-term, reversible, minor impacts perennial/tree species: short-term to long-term, reversible*, minor to major impacts</td>
<td>high</td>
<td>annual species: high perennial/tree species: low</td>
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<tr>
<td>regeneration index of indicator species</td>
<td>annual species: very short to relatively short perennial/tree species: relatively long to very long</td>
<td>strongly related</td>
<td>annual species: short-term, reversible, minor impacts perennial/tree species: short-term to long-term, reversible*, minor to major impacts</td>
<td>high</td>
<td>annual species: high perennial/tree species: low</td>
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<tr>
<td>phenology and productivity (canopy fullness/dead branches/epicormic growth)</td>
<td>annual species: very short to relatively short perennial/tree species: relatively long to very long</td>
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<td>annual species: short-term, reversible, minor impacts perennial/tree species: short-term to long-term, reversible*, minor to major impacts</td>
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<td>annual species: high perennial/tree species: low</td>
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<td>Relationship with groundwater levels</td>
<td>Risk to the environment characterised</td>
<td>Cost-effectiveness and practicality</td>
<td>Early warning capabilities</td>
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<td>annual species: short-term, reversible, minor impacts perennial/tree species: short-term to long-term, reversible*, minor to major impacts</td>
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<td>annual species: high perennial/tree species: low</td>
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<td>Environmental parameters</td>
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<tr>
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<td>Relationship with groundwater levels</td>
<td>Risk to the environment characterised</td>
<td>Cost-effectiveness and practicality</td>
<td>Early warning capabilities</td>
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<td>degree of oxygenation</td>
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<td>partly related to strongly related</td>
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<td>sulphides and sulphate</td>
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<td>short-term to long-term, reversible*, minor to major impact</td>
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<td>conductivity</td>
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<td>heavy metals</td>
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<td>na</td>
<td>short-term to long-term, reversible*, minor to major impact</td>
<td>low to high</td>
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</table>

**Water quality**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>‘Lag’ effect between depressed groundwater levels and environmental condition and/or health</th>
<th>Relationship with groundwater levels</th>
<th>Risk to the environment characterised</th>
<th>Cost-effectiveness and practicality</th>
<th>Early warning capabilities</th>
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<tr>
<td>pH</td>
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<td>strongly related</td>
<td>short-term to long-term, reversible, minor to major impact</td>
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<td>high</td>
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<tr>
<td>conductivity</td>
<td>relatively short</td>
<td>strongly related</td>
<td>short-term to long-term, reversible, minor to major impact</td>
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<tr>
<td>TOC</td>
<td>relatively short</td>
<td>strongly related</td>
<td>short-term to long-term, reversible, minor to major impact</td>
<td>high</td>
<td>high</td>
</tr>
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<td>hardness</td>
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<td>partly related to strongly related</td>
<td>short-term to long-term, reversible, minor to major impact</td>
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<td>low-high</td>
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<tr>
<td>salinity</td>
<td>relatively short</td>
<td>strongly related</td>
<td>short-term to long-term, reversible, minor to major impact</td>
<td>high</td>
<td>high</td>
</tr>
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<td>nutrient concentrations</td>
<td>relatively short</td>
<td>strongly related</td>
<td>short-term to long-term, reversible, minor to major impact</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>DO/temperature profiles</td>
<td>relatively short</td>
<td>strongly related</td>
<td>short-term to long-term, reversible, minor to major impact</td>
<td>high</td>
<td>high</td>
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<td>chlorophyll a</td>
<td>relatively short</td>
<td>strongly related</td>
<td>short-term to long-term, reversible, minor to major impact</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Criteria</td>
<td>‘Lag’ effect between depressed groundwater levels and environmental condition and/or health</td>
<td>Relationship with groundwater levels</td>
<td>Risk to the environment characterised</td>
<td>Cost-effectiveness and practicality</td>
<td>Early warning capabilities</td>
</tr>
<tr>
<td>----------</td>
<td>----------------------------------------------------------------------------------------</td>
<td>-----------------------------------</td>
<td>--------------------------------------</td>
<td>-----------------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>GDE component &amp; monitoring parameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>‘Lag’ effect between depressed groundwater levels and environmental condition and/or health</td>
<td>partly related to strongly related</td>
<td>short-term to long-term, reversible*, major impact</td>
<td>high</td>
<td>low to high</td>
<td></td>
</tr>
<tr>
<td>Relationship with groundwater levels</td>
<td>partly related to strongly related</td>
<td>long-term, reversible, minor to major impact</td>
<td>high</td>
<td>low</td>
<td></td>
</tr>
<tr>
<td>Risk to the environment characterised</td>
<td>partly related</td>
<td>long-term, reversible, minor to major impact</td>
<td>high</td>
<td>low</td>
<td></td>
</tr>
<tr>
<td>Relationship with groundwater levels</td>
<td>partly related</td>
<td>long-term, reversible, minor to major impact</td>
<td>high</td>
<td>low</td>
<td></td>
</tr>
<tr>
<td>Risk to the environment characterised</td>
<td>partly related</td>
<td>long-term, reversible, minor to major impact</td>
<td>high</td>
<td>low</td>
<td></td>
</tr>
<tr>
<td>Criteria</td>
<td>‘Lag’ effect between depressed groundwater levels and environmental condition and/or health</td>
<td>Relationship with groundwater levels</td>
<td>Risk to the environment characterised</td>
<td>Cost-effectiveness and practicality</td>
<td>Early warning capabilities</td>
</tr>
<tr>
<td>PHREATOPHYTIC TERRESTRIAL VEGETATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Community level parameters</td>
<td>community distribution/zonation change</td>
<td>relatively short to very long</td>
<td>partly related</td>
<td>high</td>
<td>low to high</td>
</tr>
<tr>
<td></td>
<td>species diversity</td>
<td>relatively long to very long</td>
<td>partly related</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td></td>
<td>structural changes (i.e. height structure)</td>
<td>relatively long to very long</td>
<td>partly related</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Population level parameters</td>
<td>cover and abundance indicator species</td>
<td>annual species: very short to relatively short perennial/tree species: relatively long to very long</td>
<td>strongly related</td>
<td>annual species: short-term, reversible, minor impacts perennial/tree species: short-term to long-term, reversible*, minor to major impacts</td>
<td>high</td>
</tr>
<tr>
<td></td>
<td>evenness of indicator species</td>
<td>relatively long</td>
<td>partly related</td>
<td>high</td>
<td>annual species: high perennial/tree species: low</td>
</tr>
<tr>
<td></td>
<td>regeneration index of indicator species</td>
<td>annual species: very short to relatively short perennial/tree species: relatively long to very long</td>
<td>strongly related</td>
<td>annual species: short-term, reversible, minor impacts perennial/tree species: short-term to long-term, reversible*, minor to major impacts</td>
<td>high</td>
</tr>
<tr>
<td></td>
<td>phenology and productivity (canopy fullness/dead branches/epicormic growth)</td>
<td>annual species: very short to relatively short perennial/tree species: relatively long to very long</td>
<td>strongly related</td>
<td>annual species: short-term, reversible, minor impacts perennial/tree species: short-term to long-term, reversible*, minor to major impacts</td>
<td>high</td>
</tr>
<tr>
<td></td>
<td>distribution of indicator species along gradient</td>
<td>annual species: very short to relatively short perennial/tree species: relatively long to very long</td>
<td>strongly related</td>
<td>annual species: short-term, reversible, minor impacts perennial/tree species: short-term to long-term, reversible*, minor to major impacts</td>
<td>high</td>
</tr>
<tr>
<td>Environmental Parameters</td>
<td>soil moisture</td>
<td>relatively short</td>
<td>strongly related</td>
<td>short-term to long-term, reversible to irreversible, minor to major impact</td>
<td>low to high</td>
</tr>
<tr>
<td></td>
<td>presence of root fungi</td>
<td>na</td>
<td>weakly/unlikely to be related</td>
<td>long-term, irreversible, minor to major impact</td>
<td>low</td>
</tr>
<tr>
<td>Criteria</td>
<td>‘Lag’ effect between depressed groundwater levels and environmental condition and/or health</td>
<td>Relationship with groundwater levels</td>
<td>Risk to the environment characterised</td>
<td>Cost-effectiveness and practicality</td>
<td>Early warning capabilities</td>
</tr>
<tr>
<td>----------</td>
<td>-----------------------------------------------------------------------------------------</td>
<td>-------------------------------------</td>
<td>--------------------------------------</td>
<td>-------------------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>records of past fire events</td>
<td>na</td>
<td>indirectly related</td>
<td>short-term to long-term, reversible to irreversible, minor to major impact</td>
<td>low to high</td>
<td>na</td>
</tr>
</tbody>
</table>

**THREATENED ECOLOGICAL COMMUNITIES**

**Cave Spring Communities**
- As for *Macroinvertebrates and water quality*
- Groundwater levels upstream of caves: very short to relatively short
- Condition of Tuart root mats: relatively short

**Tumulus Mound Springs**
- As for *Macroinvertebrates and water quality*
- Groundwater levels upstream of springs: very short to relatively short

**FROGS, REPTILES, BIRDS AND MAMMALS**

**Frogs**
- Population structure (noting proportion of metamorphs): relatively short

**Reptiles**
- Landscape scale distribution (particularly of long-necked tortoise): very long

**Landbirds and mammals**
- Landscape scale distribution: relatively short to relatively long

**Waterbirds**
- Abundance at GDE dependent habitats: relatively short to relatively long

*Note: although ecological changes may theoretically be reversible, some changes, such as in the invasion of a weed species, may require such efforts (ecological, social and economic) to reverse the impacts that for all intents and purposes, the changes are irreversible.*
3. REVIEW OF GDE MONITORING ON THE GNANGARA AND JANDAKOT MOUNDS

Details of the ecological monitoring programs associated with the management of GDE components in the study area, are presented in the following sections.

3.1 Wetland vegetation monitoring

3.1.1 Current monitoring on the Gnangara Mound

Monitoring locations and objectives

Wetland vegetation monitoring is undertaken at 19 wetlands on the Gnangara mound (see Loomes et al. 2001). These wetlands and the years monitoring commenced are outlined in Table 2. Of these, 12 are criteria wetlands (see Table 2), at which environmental water requirements (EWRs) were established as part of the Section 46 Review of Proposed Environmental Conditions for the Gnangara Mound Groundwater Resource (Section 46) (WAWA 1995).

The objective of monitoring at criteria wetlands is to document any changes in fringing and emergent vegetation, and to determine if any observed changes are related to alterations of the groundwater regime or to other factors affecting the wetlands.

Rapid assessment monitoring is carried out at the Lexia Mitigation Wetlands (LMW) 104, 132, 156, 158 and 164, by the Water Corporation of Western Australia (WC). This monitoring program is designed to detect any loss of vegetation values in these wetlands. Annual assessments are also conducted in order to describe any changes in water depth ranges of key wetland species and to predict further changes in vegetation condition under a changing water regime (Froend and Loomes 2003).

A further two non-criteria wetlands, Coogee Spring and Pipidinny Swamp, have been subject to one-off assessments of wetland vegetation as part of the Section 46 review process (see Loomes and Froend 2001a; Loomes and Froend 2001b).

Table 2: Wetland vegetation monitoring locations on the Gnangara Mound.

<table>
<thead>
<tr>
<th>Wetland monitored</th>
<th>Criteria/non-criteria wetland</th>
<th>Year monitoring commenced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Joondalup</td>
<td>Criteria</td>
<td>1995</td>
</tr>
<tr>
<td>Lake Jandabup</td>
<td>Criteria</td>
<td>1995</td>
</tr>
<tr>
<td>Lake Mariginiup</td>
<td>Criteria</td>
<td>1996</td>
</tr>
<tr>
<td>Lake Nowergup</td>
<td>Criteria</td>
<td>1996</td>
</tr>
<tr>
<td>Lake Wilgarup</td>
<td>Criteria</td>
<td>1997</td>
</tr>
<tr>
<td>Lake Yonderup</td>
<td>Criteria</td>
<td>1997</td>
</tr>
<tr>
<td>Lake Goolellal</td>
<td>Criteria</td>
<td>1997</td>
</tr>
<tr>
<td>Melaleuca Park EPP 173</td>
<td>Criteria</td>
<td>1997</td>
</tr>
<tr>
<td>Wetland monitored</td>
<td>Criteria/non-criteria wetland</td>
<td>Year monitoring commenced</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-------------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>Dampland 78</td>
<td>Criteria</td>
<td>1997</td>
</tr>
<tr>
<td>Lexia 86</td>
<td>Criteria</td>
<td>1997</td>
</tr>
<tr>
<td>Lexia 94</td>
<td>Criteria</td>
<td>1997</td>
</tr>
<tr>
<td>Lexia186</td>
<td>Criteria</td>
<td>1997</td>
</tr>
<tr>
<td>Lexia104</td>
<td>WC LMW</td>
<td>1999</td>
</tr>
<tr>
<td>Lexia132</td>
<td>WC LMW</td>
<td>1999</td>
</tr>
<tr>
<td>Lexia 156</td>
<td>WC LMW</td>
<td>2000</td>
</tr>
<tr>
<td>Lexia 158</td>
<td>WC LMW</td>
<td>2000</td>
</tr>
<tr>
<td>Lexia 164</td>
<td>WC LMW</td>
<td>2000</td>
</tr>
<tr>
<td>Coogee Springs</td>
<td>Non-criteria</td>
<td>2001 (one-off)</td>
</tr>
<tr>
<td>Pipidinny Swamp</td>
<td>Non-criteria</td>
<td>2001 (one-off)</td>
</tr>
</tbody>
</table>

**Monitoring regime**

Wetland vegetation monitoring at the 12 criteria wetlands on the Gnangara mound is undertaken annually in spring. At each of these wetlands, permanent, 10m wide belt transects, extending to the limit of emergent macrophytes, have been established. Transects are divided into 3 to 5 plots, 10m wide and 10m or 20 m long, depending on the density of trees (see Loomes et al. 2001). Measured within each plot are:

- position of each tree (recorded as a coordinate within the plot);
- diameter of each tree at breast height (DBH) (1.5m above ground);
- species richness;
- crown health (density of crown, number of dead branches and presence of epicormic growth is assessed and for each of these components a score is given (see Ladd (1996) for scoring scale). Scores are totalled to give a health assessment score for each tree);
- cover and abundance for all species identified within each plot (using the Domin-Krajina scale (Kent and Coker 1992));
- weediness index (calculated as the transformed cover of exotic species divided by the transformed cover of native species);
- presence of seedlings, saplings and resprouts are recorded for overstorey species, from which a regeneration index is calculated (by dividing number of seedlings by the number of trees, plus one, in the plot).

The monitoring regime described above is also applied to the one-off assessments of the non-criteria wetlands, Coogee Spring and Pipidinny Swamp.

Rapid assessment of vegetation condition is undertaken at LMWs 104, 132, 156, 158 and 164. This involves fortnightly assessments during dry months (January-March).
and monthly assessments throughout the remainder of the year (Froend and Loomes 2003a). The fortnightly assessments record:

- vegetation condition and structure assessment along shallow observation bore transect lines at each wetland. As transect lengths may be up to 270m, assessment is limited to separate 10m by 10m plots at each of the monitoring bores and only at bores which have wetland vegetation species present (Froend and Loomes 2003a);

- cover and abundance, health of overstorey wetland species, a weediness index and the presence of seedlings, saplings or resprouts (following the methodology described previously for criteria wetland monitoring).

Since 2002, additional annual assessments of the LMWs have been undertaken in June in order to describe any changes in water depth ranges of key wetland species. This involves full vegetation surveys, as described above for criteria wetland vegetation monitoring.

3.1.2 Current monitoring on the Jandakot Mound

Monitoring locations and objectives

Wetland vegetation monitoring is undertaken at 9 wetlands on the Jandakot mound. These wetlands and the years monitoring commenced are detailed in Table 3. As with wetland vegetation monitoring on the Gnangara mound, the objectives of monitoring are to determine if there have been any changes in the condition of the vegetation over time, and if this is related to alterations of the groundwater regime or to other factors affecting the wetlands (Ladd 1999).

Table 3: Wetland vegetation monitoring locations on the Jandakot Mound.

<table>
<thead>
<tr>
<th>Wetlands monitored</th>
<th>Year monitoring commenced</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Lake</td>
<td>1996</td>
</tr>
<tr>
<td>Bibra Lake</td>
<td>1996</td>
</tr>
<tr>
<td>Kogolup Lake (Nth)</td>
<td>1996</td>
</tr>
<tr>
<td>Kogolup Lake (Sth)</td>
<td>1996</td>
</tr>
<tr>
<td>Thomsons Lake</td>
<td>1996</td>
</tr>
<tr>
<td>Lake Banganup</td>
<td>1996</td>
</tr>
<tr>
<td>Shirley Balla Swamp</td>
<td>1996</td>
</tr>
<tr>
<td>Twin Bartram Swamp</td>
<td>1996</td>
</tr>
<tr>
<td>Beenyup Rd Swamp</td>
<td>1996</td>
</tr>
</tbody>
</table>
Monitoring regime

The monitoring regime for wetlands on the Jandakot mound is similar to that for wetlands on the Gnangara mound. Monitoring is undertaken annually in spring/summer. At each wetland, permanent transects, 10m wide and 40m to 100m long (depending on site characteristics and vegetation present) have been established. Transects are further divided into 4 segments and 3 randomly placed 1m² plots are located in each segment. The parameters measured within each transect are the same as those measured at the criteria wetlands on the Gnangara mound (see Section 3.1.1).

3.2 Macroinvertebrate, water quality and wetland soils monitoring

3.2.1 Current monitoring on the Gnangara Mound

Monitoring locations and objectives

Macroinvertebrate and water quality monitoring is carried out at 14 wetlands on the Gnangara Mound. These wetlands and the years monitoring commenced are presented in Table 4.

The stated objective of the wetland macroinvertebrate monitoring program on the Gnangara mound is to describe the status of aquatic macroinvertebrates in terms of family richness and community structure, and their response to changes in water quality and water levels (see Benier and Horwitz 2003). The principal purpose of monitoring has always been to devise a measurement protocol with the ability to detect any change to the water regime that results in undesirable consequences for water quality and/or macroinvertebrate assemblages.

Table 3: Macroinvertebrate and water quality monitoring locations on the Gnangara Mound.

<table>
<thead>
<tr>
<th>Wetland monitored</th>
<th>Year monitoring commenced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Joondalup (Nth and Sth)</td>
<td>1996</td>
</tr>
<tr>
<td>Lake Jandabup</td>
<td>1996</td>
</tr>
<tr>
<td>Lake Mariginiup</td>
<td>1996</td>
</tr>
<tr>
<td>Lake Nowergup</td>
<td>1996</td>
</tr>
<tr>
<td>Lake Wilgarup</td>
<td>1996</td>
</tr>
<tr>
<td>Lake Yonderup</td>
<td>1996</td>
</tr>
<tr>
<td>Lake Goollelal</td>
<td>1996</td>
</tr>
<tr>
<td>Loch McNess (Nth and Sth)</td>
<td>1996</td>
</tr>
<tr>
<td>Lake Gnangara</td>
<td>1996</td>
</tr>
<tr>
<td>Coogee Spring</td>
<td>1996</td>
</tr>
<tr>
<td>Pipidinny Swamp</td>
<td>1996</td>
</tr>
<tr>
<td>Melaleuca Park EPP 173</td>
<td>2000</td>
</tr>
<tr>
<td>Lexia 86</td>
<td>2000</td>
</tr>
<tr>
<td>Lexia 186</td>
<td>2000</td>
</tr>
</tbody>
</table>
Monitoring Regime

Macroinvertebrate and water quality monitoring takes place twice a year, in late winter/early spring (when water levels and biological activity are at their presumed highest in wetlands), and in late summer/early autumn (when water levels at permanent wetlands are at their lowest, or shortly before ephemeral wetlands dry out) when major stress on fauna occurs (Sommer and Horwitz 1998). This sampling regime is intended to maximise, in a standard way, the macroinvertebrate diversity found at wetlands according to their life histories (Clark and Horwitz 2004).

Sites at all wetlands are chosen on the basis of habitats present, dominant habitats provide the basis for stratified sampling. Habitats sampled are those identified principally by their vegetation structure, for instance: *Baumea articulata*, *Typha orientalis*, other *Baumea* spp., inundated *Melaleuca raphiophylla*, sword sedge (*Lepidosperma* sp.), mixed sedge communities (*Restionaceae/Cyperaceae* dominated) and open water (with or without submerged macrophytes). Where open water is sampled, preference is usually given to areas with beds of submerged macrophytes (such as *Ruppia*, *Chara* or *Villarsia*) as these habitats tend to have higher invertebrate diversity than open water over bare sediment, and therefore a better representation of the macroinvertebrate fauna present in a wetland can be achieved.

Sampling protocol follows Chessman’s (1995) ‘rapid assessment’ method. Selective sampling is carried out in fixed locations, in three of the most dominant habitat types at each wetland. As water levels at a given location vary between and within seasons, sampling occurs (where possible) when a specified water level is reached rather than at a given date. This ensures the same sampling locations within a wetland can be sampled each round. Lake Jandabup, Lake Nowergup and Loch McNess are sampled more intensively as they are of critical importance to the Water and Rivers Commission. In each of these lakes five habitats are sampled.

Sampling methodology is as follows:

- 2 minute sweeps are made through all depths, with a 250µm D-framed net. In dense algae or fine organic matter a 500µm net is used. The technique used depends on the habitat being sampled: in bare substrate and submerged macrophyte habitats, the sweep net is moved in a zigzag motion from the water surface to the lake bed; in the emergent macrophyte habitat the net is vigorously forced through the macrophytes from the bases of the plants to the water surface; in the *Melaleuca* habitat, the net is swept amongst overhanging branches.

- samples are washed then live picked in a white tray ‘on-site’ for 30 minutes to obtain 100 animals per habitat. Where few invertebrates are present in any one sweep, further samples are collected and picked until the thirty minute time period expires. A maximum of 10 individuals per taxa are collected and log abundance and Chessman (1995) type abundance scores recorded.

- all animals are placed in 100% ethanol in the field and upon return to the laboratory samples are rinsed and stored in 70% ethanol. Once in the laboratory all invertebrates are identified to at least to Family level with the exception of some groups such as the Oligochaeta, Turbellaria, Porifera, Nematoda etc. Family richness counts are compiled for each sampling site and for each wetland.
• environmental parameters measured in-situ are as follows: pH, conductivity, temperature, DO (mg/L and % saturation) and mean depth for each site. Measurements are taken just below the water surface as well as near the benthos using well maintained and calibrated field meters.

• habitat complexity is described by recording percentage composition of bare substrate, submerged macrophytes, emerged macrophytes, algae, detritus etc., and the density of each component is scored (on a scale from 1 to 5). Notes are taken regarding substrate type, weather, time of sampling and a macrophyte sample from each habitat is taken for identification as required. A photographic record of each site is also made.

• at each site two one litre samples of water are collected from just below the surface in opaque one litre bottles, without air, for chemical analysis. The samples are combined for each site and the bulked sample used for analysis. Chlorophyll-a, nitrate/nitrite, orthophosphate, total nitrogen, total phosphorus, colour (gilvin or soluble humic colour) and formazin turbidity (FTU) are all measured.

• for chlorophyll $a$, between 500 and 1000 ml of water is filtered through a 0.45μm glass fibre filter (47 mm diameter) on the day of collection. The filter is put in a plastic sachet, wrapped in alum inum foil and frozen until processing. Chlorophyll $a$ content is determined spectrophotometrically after acetone extraction at 750, 664 647 and 630 nm. The filtrate from the chlorophyll $a$ extraction, as well as 250 ml unfiltered water, are immediately frozen until nutrient analyses can be carried out. Nutrients have been commissioned to an authorized Laboratory for analysis. Nitrate/nitrite, ammonia and orthophosphate are measured on filtered water. Total nitrogen and total phosphorus are measured on unfiltered water.

• colour (Gilvin, or soluble humic colour) is determined photospectrometrically from filtered water at an absorbance of 440 nm. Formazin turbidity (FTU) is measured at 450 nm wavelength on the day of collection (unfiltered water) using a spectrophotometer.

Analysis and Interpretation of Monitoring Data

Macroinvertebrate data have in the past been tabulated in order to produce richness statistics for each wetland, for each sampling round. Qualitative examination of presence/absence data enables comparisons to be made between seasons and between years to examine patterns of change, and between those wetlands known to be impacted by various disturbances and those relatively unimpacted ‘control’ wetlands.

Classification and ordination is undertaken where necessary to examine patterns of similarity over time, while indices of sensitivity for macroinvertebrates are used to gain an understanding of the relative degree of disturbance an assemblage has suffered.

3.2.2 Current monitoring on the Jandakot Mound

Monitoring locations and objectives

Macroinvertebrate and water quality monitoring is carried out at 9 wetlands on the Jandakot mound. These locations and the years monitoring commenced are detailed in Table 5.
The objective of the monitoring program is to provide an indication of whether existing and proposed groundwater abstraction schemes together with private groundwater abstraction, are having an impact on the identified ecological values of wetlands (Wild and Davis 2004).

Forrestdale Lake and Lake Balannup were included in the monitoring program from spring 2001, following recommendations by McGuire et al. (1999) to increase the number of reference wetlands, those less influenced by the abstraction of groundwater, that are monitored. This was to ensure differences between undisturbed wetlands and those potentially affected by groundwater abstraction can be statistically tested (as the previous control wetland, Warton Rd Swamp, was becoming less distinct from the remaining wetlands).

Table 4: Macroinvertebrate and water quality monitoring locations on the Jandakot Mound.

<table>
<thead>
<tr>
<th>Wetlands monitored</th>
<th>Year monitoring commenced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thomsons Lake</td>
<td>1996</td>
</tr>
<tr>
<td>Lake Kogolup North</td>
<td>1996</td>
</tr>
<tr>
<td>Lake Kogolup South</td>
<td>1996</td>
</tr>
<tr>
<td>Yangebup Lake</td>
<td>1996</td>
</tr>
<tr>
<td>Lake Banganup</td>
<td>1996</td>
</tr>
<tr>
<td>Shirley Balla Swamp</td>
<td>1996</td>
</tr>
<tr>
<td>Gibbs Rd Swamp</td>
<td>1996</td>
</tr>
<tr>
<td>Warton Rd Swamp</td>
<td>1996</td>
</tr>
<tr>
<td>Forrestdale Lake</td>
<td>2001</td>
</tr>
<tr>
<td>Balannup Lake</td>
<td>2001</td>
</tr>
</tbody>
</table>

Monitoring regime

The macroinvertebrate and water quality monitoring for wetlands on the Jandakot mound follows a similar regime to that of the Gnangara mound program. Monitoring occurs twice each year, during spring and during autumn/summer. Dominant habitats are identified at each wetland and macroinvertebrate samples and water quality samples collected. Dominant habitats included bare substrate, submerged macrophytes, mixed sedge communities, Typha beds, Baumea beds, Melaleuca raphiophylla, floating macrophytes, mixed sedge communities and other emergent communities (Wild and Davis 2004).

Sampling methodologies follow the same procedures as described above for the Gnangara mound monitoring program (see Section 3.2.1), with the exception of the number of individuals live picked in-situ (200 animals) and with the length of time for which additional samples are live picked (where few invertebrates are present in the initial sweep additional samples are live picked for a further 20 minutes).

Photographs have been taken at standard reference points (marked on maps, see Wild and Davis (2004)) at each wetland between January 1998 and January 2004. These
photos record changes that have occurred in the water levels and vegetation (Wild and Davis 2004).

### 3.3 Phreatophytic terrestrial vegetation monitoring

#### 3.3.1 Current monitoring on the Gnangara Mound

**Monitoring locations objectives**

Triennial phreatophytic vegetation monitoring is carried out at 17 locations on the Gnangara Mound. Locations have been selected to represent areas near current pumping (i.e. Gnangara P50 and Whiteman Park), beyond the immediate influence of pumping (i.e. Bombing Range, Neaves and Tangletoe) and near proposed pumping operations (i.e. Bell, Melaleuca and Yanchep) (Mattiske 2003). Transect relocation/re-pegging was recently considered for nine monitoring sites on the Gnangara mound (namely Bell, Melaleuca, Neaves, Gnangara P50, Tangletoe, Tick Flat, Whiteman Park, Yanchep and Yeal) and an additional monitoring site was also established (Bombing Range) (Mattiske 2003).

The general objective of phreatophytic vegetation monitoring is to relate vegetation condition to soil moisture, climate and pumping operations. In the annual reports, specific objectives are described for the monitoring program each year, referring to the relocation and/or re-pegging of established transects and the establishment of new transects as necessary.

Monitoring locations and the years monitoring occurs are presented in Table 6.

#### Table 5: Phreatophytic vegetation monitoring locations on the Gnangara Mound.

<table>
<thead>
<tr>
<th>Transect location</th>
<th>Year monitored</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Kendall</td>
<td>66, 76, 78-81, 84, 87, 90, 96, 97</td>
</tr>
<tr>
<td>West Gironde</td>
<td>66, 76, 78-81, 84, 87, 90, 98</td>
</tr>
<tr>
<td>Neaves</td>
<td>66, 76, 78-81, 84, 87, 90, 93, 97, 99, 02</td>
</tr>
<tr>
<td>Tick Flat</td>
<td>66, 76, 78-81, 84, 87, 90, 93, 96, 02</td>
</tr>
<tr>
<td>Lake Joondalup</td>
<td>66, 76, 78-81, 84, 87, 90</td>
</tr>
<tr>
<td>Jandabup Lake</td>
<td>76, 78-81, 84, 87, 90, 93,97, 99</td>
</tr>
<tr>
<td>Nowergup</td>
<td>87, 90, 97</td>
</tr>
<tr>
<td>Yanchep</td>
<td>87, 90, 93, 97, 99, 02</td>
</tr>
<tr>
<td>Ridges</td>
<td>87, 90, 96</td>
</tr>
<tr>
<td>Yeal Swamp</td>
<td>87, 90, 93, 96, 97, 02</td>
</tr>
<tr>
<td>Tangletoe</td>
<td>87, 90, 97, 99, 02</td>
</tr>
<tr>
<td>Gnangara P50</td>
<td>88, 93, 96, 97, 99, 02</td>
</tr>
<tr>
<td>Whiteman Park</td>
<td>91, 96, 99, 02</td>
</tr>
<tr>
<td>Bell (Lexia 86)</td>
<td>96, 99, 02</td>
</tr>
</tbody>
</table>
### Monitoring Regime

Triennial monitoring takes place during spring at each monitoring location. The layout of the permanent transects is based on the pattern established by Havel (1968). Transects are located to maximise coverage from the dune crest to a swamp or depression (Mattiske 2003).

Tree species are recorded in two 20m by 20m plots located either side of the transect line and are permanently tagged to increase accuracy of future monitoring (Mattiske 2003). Understorey species are recorded in quadrats 4m by 4m, located at regular intervals within the larger plots (Mattiske 2003). The following measurements are recorded within each of the larger plots:

- stem diameter at breast height (DBH) of all tree species present.
- condition of each stem (H= healthy, S= sick or stressed, VS= very stressed, D= dead).
- seedlings (young tree below 130cm) and side branches also noted.

Tree results are summarised for each species and relative frequency, tree numbers, stem numbers and condition are described.

Within each smaller 4m by 4m quadrat, the following are measured:

- presence or absence of all understorey species.
- density (alive and dead) and percentage foliage cover of understorey species.

The total number of living plants and percentage frequency results are also summarised for all perennial species.

Soil moisture was previously monitored at transects between September and October, when water table levels were seasonally high after winter rains. Soil moisture however, has not been monitored in the last few years due to high costs.

### 3.3.2 Current monitoring on the Jandakot Mound

**Monitoring locations and objectives**

Terrestrial vegetation monitoring has been carried out at 5 locations on the Jandakot mound since 1988. Transects were established to cover a range of locations, both near current and proposed locations (i.e. Thomsons Lake, Airport and Liddelow) as well as beyond the immediate influence of pumping (i.e. Modong East and Modong West) (Mattiske 2001).

The objective of phreatophytic vegetation monitoring on the Jandakot mound, as with monitoring on the Gnangara mound, is to relate vegetation condition to soil moisture, climate and pumping operations. Individual reports outline specific monitoring objectives for each year, referring to the relocation and/or re-pegging of established transects, and the establishment of new transects as necessary.

---

<table>
<thead>
<tr>
<th>Transect location</th>
<th>Year monitored</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maralla (Lexia 186)</td>
<td>96, 99</td>
</tr>
<tr>
<td>Melaleuca</td>
<td>96, 99, 02</td>
</tr>
<tr>
<td>Bombing Range</td>
<td>02</td>
</tr>
</tbody>
</table>
Monitoring locations and the years monitoring occurs are presented in Table 7.

Table 6: Phreatophytic vegetation monitoring locations on the Jandakot Mound.

<table>
<thead>
<tr>
<th>Transect location</th>
<th>Year monitoring commenced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thomsons Lake</td>
<td>1988</td>
</tr>
<tr>
<td>Airport</td>
<td>1988</td>
</tr>
<tr>
<td>Liddelow</td>
<td>1988</td>
</tr>
<tr>
<td>Modong East</td>
<td>1988</td>
</tr>
<tr>
<td>Modong West</td>
<td>1988</td>
</tr>
</tbody>
</table>

Monitoring regime

Monitoring of phreatophytic vegetation on the Jandakot mound follows the same methodology as for phreatophytic vegetation monitoring on the Gnangara mound (see Section 3.3.1). Transects at each location vary in length with Liddelow and Modong East 180m, Airport 200m, Modong West 220m, and Thomsons Lake 500m.

3.4 Current Threatened Ecological Communities monitoring

3.4.1 Cave stream communities – Current monitoring

Monitoring locations and objectives

The fauna and water quality at Boomerang, Cabaret, Twilight, Carpark and Water Caves (all within Yanchep National Park) were sampled during December 1998, before annual monitoring of these caves began in November 2000. Monitoring was undertaken the following year in September and again in January 2002, although at this stage Twilight Cave was deemed unsafe to enter and was not re-sampled (Knott and Storey 2002). Twilight Cave has not been included within the monitoring program since then. During September 2002 four new caves were sampled in addition to those previously mentioned: Cave on Lot 51 (YN555), un-named cave (YN61), Jackhammer Cave and in December 2002, Orpheus Cave (Knott and Storey 2003). During 2003, seven of the previously monitored cave stream communities were visited. Jackhammer Cave was excluded from recent monitoring as it failed to hold any fauna on previous occasions (Knott and Storey 2004). Although Boomerang Cave was visited in 2003, it was not sampled as the cave stream was dry (thought to be a result of issues relating to the maintenance of the in-cave reticulation system (Knott and Storey 2004)). An eighth cave, Fridge Grotto, was also visited in 2003 but was not sampled as it too was dry (Knott and Storey 2004). Past and present monitoring of caves is detailed in Table 8.

Gilgie Cave, which has been dry since 1996 and not included within the monitoring program, may be visited in the future if the cave stream becomes recharged (A. Storey pers. comm.). Similarly, if Twilight Cave is made safe to enter, monitoring at this site will recommence (A. Storey pers. comm.).
The objective of the cave stream monitoring program is to provide an indication of whether private groundwater abstraction and pine plantation management are having an impact on the identified ecological values of cave streams in Yanchep National Park (Knott and Storey 2004). Species composition and the presence of ‘cavernicole’ species (dependent on and endemic to the caves) are documented. Information from the monitoring program is to be used to assess the status of TECs in the cave streams and evaluate the impacts of changes in groundwater levels (Knott and Storey 2004).

Table 7: Cave stream community monitoring locations on the Gnangara Mound.

<table>
<thead>
<tr>
<th>Monitoring location</th>
<th>Years monitored</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cabaret Cave</td>
<td>1998, 2000-present</td>
</tr>
<tr>
<td>Carpark Cave</td>
<td>1998, 2000-present</td>
</tr>
<tr>
<td>Boomerang Cave</td>
<td>1998, 2000-present</td>
</tr>
<tr>
<td>Water Cave</td>
<td>1998, 2000-present</td>
</tr>
<tr>
<td>YN555 (Lot 51)</td>
<td>2002-present</td>
</tr>
<tr>
<td>YN61 (unnamed)</td>
<td>2002-present</td>
</tr>
<tr>
<td>Orpheus cave</td>
<td>2002-present</td>
</tr>
<tr>
<td>Jackhammer Cave</td>
<td>2002, presently unmonitored</td>
</tr>
<tr>
<td>Gilgi Cave</td>
<td>dry since 1996, presently unmonitored</td>
</tr>
<tr>
<td>Twilight Cave</td>
<td>1998, 2000-2001, presently unmonitored</td>
</tr>
</tbody>
</table>

**Monitoring Regime**

Sampling is timed to take place when water levels are at their highest, usually mid-spring.

The following *in-situ* water quality measures are made at each monitoring location:

- DO, turbidity, salinity, conductivity, pH, redox and water temperature.

Water samples are also collected from each site using cleaned water bottles (rinsed at each site) and the following parameters measured in the laboratory:

- calcium, potassium, magnesium, nitrate, nitrite, sodium, soluble reactive phosphorus and sulphate.

Aquatic invertebrate fauna was sampled using the modified sampling regime developed when sampling caves in mid-January 2002 (Knott and Storey 2003). The modified sampling regime was developed in response to concerns about the repeated destructive sampling of root mats when collecting aquatic invertebrates (Knott and Storey 2003). The aim of the modified technique is to collect as many species as possible while causing the least disturbance and damage to the cave root mats (Knott and Storey 2004). The methodology is as follows:
Study of EWRs on the Gnangara and Jandakot Mounds under Section 46: Tasks 3 & 5

composite sweep samples are taken across all accessible submerged root mat habitats in each cave using a small (10cm diameter), custom-made 50µm mesh net.

samples are placed in sealed, labelled plastic bags, covered with water from the site, returned to the laboratory under cool, light-tight conditions and sorted live in the laboratory under a dissecting microscope.

Water levels within the caves are monitored monthly by Water and Rivers Commission.

3.4.2 Tumulus Mound Springs – Current monitoring

Monitoring locations and objectives

Two seepages on the Gnangara mound are subject to monitoring, Egerton and Edgecombe Tumulus Springs (previously known as ‘mound springs’).

The objective of the monitoring program is to detect adverse changes in the ecology of the seepages, resulting from too rapid drawdown of the water table or increasing nutrient concentrations within the groundwater of the Gnangara mound (Horwitz and Knott 2003).

Monitoring regime

Aquatic invertebrate monitoring has been undertaken at Egerton and Edgecombe Springs during November 2000, December 2001, October 2002 and October 2003.

Fauna samples at the springs are collected at the point of discharge and along the runnels before they exit the mound (Horwitz and Knott 2003). Sediment and detritus samples are also collected, bulked and returned to the laboratory for live sorting of specimens under a dissecting microscope (Horwitz and Knott 2003).


Samples are collected in washed (not acid-washed) plastic containers and refrigerated until analysis at the Marine and Freshwater Research Laboratory, Murdoch University. Analysis of water samples is consistent with the methodologies employed in the broader monitoring program for water quality analysis on the Gnangara mound (see Section 3.2.1). Water samples are analysed for ammonium, nitrate/nitrite, total nitrogen, orthophosphate, total phosphorus, total iron and sulphate.

In 2002, a discharge-measuring station was planned for installation at the foot of Egerton Spring, with monthly checks on the discharge in order to monitor the water quality of the spring (Horwitz and Knott 2003). To date, this has not been installed.

3.5 Frog, reptile, landbird and mammal and waterbird monitoring

3.5.1 Frogs – Current monitoring on the Gnangara Mound

Monitoring locations and objectives

Monitoring of frog populations has been undertaken since 2000, in six wetlands on the Gnangara mound. In 2002 monitoring was taken over from the Department of Terrestrial Vertebrates at the Museum of Western Australia, by Bamford Consulting Ecologists. During 2003 changes were made to the monitoring program so that the
project focused more intensely on fewer wetlands and on thorough, replicable estimates of tadpole recruitment, given the importance of tadpole recruitment to frog lifecycles and sensitivity of this lifecycle stage to groundwater abstraction (Davis and Bamford 2003). Two wetlands are currently sampled for monitoring purposes, Lexia 86 and EPP Wetland 173. These sites were chosen as they are both large, natural wetlands with long hydroperiods and large areas of suitable microhabitat for frogs, as well as supporting large frog populations, as determined from previous monitoring (Davis and Bamford 2003). Monitoring ceased at the remaining sites as previous studies indicated they supported low numbers of frogs, had little free-standing water and were unsuitable for determining long-term trends (Davis and Bamford 2003). Monitoring locations and the years monitoring commenced/ceased are outlined in Table 9.

The primary aim of the monitoring program is to determine if public groundwater abstraction is affecting frog populations within the study area (Davis and Bamford 2003).

Table 8: Frog monitoring locations on the Gnangara Mound.

<table>
<thead>
<tr>
<th>Monitoring location</th>
<th>Years monitored</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lexia 86</td>
<td>2000-present</td>
</tr>
<tr>
<td>EPP Wetland 173</td>
<td>2000-present</td>
</tr>
<tr>
<td>Lexia 94</td>
<td>2000-2003</td>
</tr>
<tr>
<td>Lexia 186</td>
<td>2000-2003</td>
</tr>
<tr>
<td>Melaleuca Park Dampland 78</td>
<td>2000-2003</td>
</tr>
<tr>
<td>Lake Yakine</td>
<td>2000-2003</td>
</tr>
</tbody>
</table>

Monitoring regime

Four monitoring methods are utilised as part of the monitoring regime:

- **Pitfall trapping** (see Davis and Bamford 2003): 50 pitfall traps were installed at each site (consisting of 20L white plastic buckets with drainage holes), oriented in a ‘firewheel’ grid (5 lines of 10 traps at each wetland). The first traps of each transect are placed near high water mark and subsequent traps spaced at 30m intervals in a curving arc from the wetland. Two trap lines at each site are fenced with a 3.5m drift fence to either side of the trap. Pitfall traps were opened during two periods throughout 2003, from 11th to 16th May and from 19th to 24th October. Traps are checked each morning of the survey and any captured frogs or other vertebrates are identified to species level, measured (snout vent length) and marked with an individual toe-clip. For metamorphosing frogs a single cohort mark was given to all individuals to identify year of emergence.

- **Surveying calling males** (see Davis and Bamford 2003): audio monitoring transects were undertaken one night in September 2003, visiting each site once. Transects were divided into 10m sections, located around the wetland fringe. Each section was traversed and the number of calling males within 5m of either
side of the transects was recorded. At EPP Wetland 173 a 100m shoreline transect was established along with a 50m transect in the deeper water amongst the submerged vegetation. At Lexia 86 a 70m transect through the water (encompassing the full width of the wetland) was established.

Each wetland was also surveyed for the presence of Heleioporus eyrei breeding burrows on one occasion during May 2003 (14/05/03). Counts of the distinctive mounds of sand that mark the presence of burrows were made at each wetland.

- **Tadpole surveying** (see Davis and Bamford 2003): passive tadpole trapping was undertaken at each site to investigate the presence or absence of each species and provide a measure of abundance. Modified 2L plastic soft-drink bottles (see Richter 1995) were utilised for trapping. A calibration exercise was undertaken at EPP Wetland 173 using 26 traps placed in pairs, 10m from each other pair. Traps within each pair were at varying distances apart (from 0m to 10m) to enable estimation of ideal trapping space. This design was used in both open water and dense *Baumea* to compare the influence of the microhabitat. Results of the calibration exercise indicated an optimum distance of 4m for trap spacing and traps were subsequently established at each wetland for one night, at 4m spacings. Captured tadpoles were identified and counted before being released back in to the wetland.

- **Site descriptions**: dominant plant species and community structure were briefly described for each wetland along with a very brief description of water level patterns throughout the monitoring period.

3.5.2 Waterbirds – Current monitoring on the Gnangara Mound

Waterbird monitoring is currently not undertaken at wetlands on the Gnangara mound, although opportunistic waterbird counts were carried out at wetlands on the Gnangara mound by volunteers during the 1980s (M. Bamford pers. comm.).

3.5.3 Frogs, reptiles, landbirds and mammals – Current monitoring on the Jandakot Mound

Frog, reptile, landbird and mammal monitoring is not undertaken at wetlands on the Jandakot mound.

3.5.4 Waterbirds – Current monitoring on the Jandakot Mound

**Monitoring locations and objectives**

Waterbird monitoring has been conducted at 12 wetlands on the Jandakot mound since 1996. Monitoring locations are presented in Table 10. There is current uncertainty as to whether or not the waterbird monitoring program will be continued during 2004 (M. Bamford pers. comm.).

The aim of the waterbird monitoring is to gather information on waterbird usage of wetlands that are influenced by the Jandakot mound, so that impacts of current or future groundwater abstraction can be assessed (Bamford and Bamford 2002). Through monitoring it is intended to build up a picture of the relationships between wetland water levels and waterbird abundance and usage, so as to understand and minimise potential impacts of water level changes (Bamford and Bamford 2002).
Table 9: Waterbird monitoring locations on the Jandakot Mound.

<table>
<thead>
<tr>
<th>Monitoring location</th>
<th>Year monitoring commenced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Forrestdale</td>
<td>1996</td>
</tr>
<tr>
<td>Thomsons Lake</td>
<td>1996</td>
</tr>
<tr>
<td>Lake Kogolup (north and south)</td>
<td>1996</td>
</tr>
<tr>
<td>Lake Yangebup</td>
<td>1996</td>
</tr>
<tr>
<td>Bibra Lake</td>
<td>1996</td>
</tr>
<tr>
<td>Gibbs Rd Swamp</td>
<td>1996</td>
</tr>
<tr>
<td>Bartram Rd Swamp</td>
<td>1996</td>
</tr>
<tr>
<td>Gil Cahalwell Reserve</td>
<td>1996</td>
</tr>
<tr>
<td>Mather Reserve</td>
<td>1996</td>
</tr>
<tr>
<td>Shirley Balla Swamp</td>
<td>1996</td>
</tr>
<tr>
<td>Twin Bartram Swamp</td>
<td>1996</td>
</tr>
<tr>
<td>The Spectacles</td>
<td>1996</td>
</tr>
</tbody>
</table>

**Monitoring regime**

Waterbird monitoring is conducted during the autumn/winter period and again during the spring/summer period, at approximately the same time each year, relative to the water cycle (Bamford and Bamford 2002). Surveys are timed to coincide with critical periods for waterbird usage and when wetlands contain water. Autumn/early winter surveys take place when wetlands are just beginning to fill with water following the first winter rains and early spring surveys take place when water levels are high and waterbirds are usually breeding. Late spring/early summer surveys takes place when water levels are low and waterbirds are concentrated on the wetlands containing the most water.

Each site survey involves a total count of all waterbird species present (limited where dense vegetation restricts access and visibility and for cryptic species), by walking and wading around and through each wetland, using the following methods:

- the number of waterbirds in very large flocks is estimated by counting the number of birds within a unit of the flock, and then estimating the number of such units within the flock;
- when large flocks contain several species, numbers of individuals of different species are estimated by determining a total flock size and a proportion for each species.

Bamford and Bamford (2002) note that the above methods of estimating total counts are more accurate than attempting to count every single bird in a moving mixed species flock. Large wetlands and wetlands with separate sections are divided into sectors for counting purposes and results pooled for each wetland.

Activity and habitat of waterbirds is also recorded in addition to total number counts, in order provide information of how waterbirds use wetlands on the Jandakot mound. Activity was recorded using the following categories:
• birds scored as active (foraging) or inactive (sleeping/loafing on the water/etc) or overhead (flying through the site, except for the Swamp Harrier which was classed as active (foraging) when overhead);  

Habitat categories assigned to waterbirds include:  
• shore/shallows: includes birds on sand, rock or mud within about 5m of the water’s edge, birds within 20m of the shoreline, and birds on or within 20m of sandbars;  
• open water: water more than 20m from any shoreline in which birds were obviously swimming;  
• fringing vegetation: water under a dense canopy of flooded trees, lawn, sedges, rushes and perches (dead or alive);  
• birds flying through a site were not assigned to a habitat (although Swamp Harriers were assigned the habitat category over which they were foraging).  

A broad definition of waterbirds is used in this monitoring program to include species such as the Swamp Harrier and White-fronted Chat. Although such species are not traditionally considered waterbirds, they are closely associated with wetlands (Bamford and Bamford 2002). Other fauna species are listed opportunistically.  

Opportunistic and systematic searching for breeding records are also undertaken at all sites, recording:  
• presence of broods of dependent young, conspicuous with most waterbirds;  
• size and estimated age of broods;  

Nest searches are made in the same general area at each wetland and nest materials, locations and contents are recorded. In large wetlands intensive nest searching is restricted to a portion of the wetland, while at The Spectacles access difficulties and the threat of disturbing and harming nesting waterbirds restricts nest searches (Bamford and Bamford 2002).  

### 3.6 Current surface water and groundwater level monitoring – Gnangara and Jandakot Mounds

**Monitoring locations and objectives**

The Water and Rivers Commission currently monitors approximately 1300 bores on the Gnangara and Jandakot mounds, collecting around 7100 water level readings annually (Aquaterra 2004).  

Aquaterra (2004) provide a summary of current monitoring within groundwater management areas and for individual aquifers, in a review of groundwater monitoring designed to assess the extent and condition of the current network and make recommendations as to any changes that may need to be introduced. This review also considered the adequacy of monitoring networks associated with groundwater dependent wetlands, based on conclusions of a study undertaken by Rockwater (2003), which was designed to investigate the relationship between groundwater levels and wetland levels on the mounds. The Rockwater (2003) study reviewed 28 monitoring sites, 18 on the Gnangara mound and 10 on the Jandakot mound.
The current network of monitoring bores and staffs has been established over the last 35 years in response to a number of issues: drainage programs; management of borefields on the Gnangara and Jandakot Mounds; the preservation of wetland habitats; and environmental concerns about possible impacts of groundwater abstraction on wetlands, vegetation and cave systems (Rockwater 2003). Rockwater (2003) suggest the number of issues and objectives which have driven the development of the network of monitoring bores, has led to the construction of bores and measuring staffs which are not of uniform standard and in some cases are inappropriately located and constructed (Rockwater 2003) (see Section 4.6 for details). See Aquaterra (2004) for a brief summary of the history of the monitoring network and subsequent reviews.

**Monitoring regime**

During the mid-1980s water levels in bores and wetlands were recorded monthly at around 900 sites throughout the Gnangara Mound (WAWA 1986). Monitoring is carried out either monthly or bi-annually (during April/May and October), however the frequency can vary depending on bore location and the specific purpose of monitoring. For example, monitoring frequency is increased when and where environmental criteria are breached (Aquaterra 2004).

The vast majority of monitoring bores monitor watertable levels of the superficial aquifer of the Gnangara and Jandakot Mounds. Less than 300 monitoring bores monitor the deeper confined aquifers (Mirrabooka, Leederville and Yarragadee aquifers) (see Aquaterra (2004) for breakdown of monitoring bores within each aquifer).

### 4.0 LIMITATIONS AND KNOWLEDGE GAPS

Finlayson and Mitchell (1999) note that overcoming the sectoral approach to research and monitoring is one of the key challenges in preventing further loss and degradation of wetlands and of GDEs generally. Van Dam *et al.* (1998) stress it is imperative to adopt a holistic approach when assessing potential impacts on wetlands, given the spatial and temporal complexity many of these systems exhibit. The importance of a coherent and holistic approach to wetland monitoring is also emphasised by Finlayson (2003) and is equally relevant to the monitoring of other GDEs, such as phreatophytic vegetation. These issues are pertinent to the monitoring of GDEs on the Gnangara and Jandakot mounds. The division of monitoring of GDE components between and within the mounds (i.e. wetland vegetation monitoring, macroinvertebrate monitoring, phreatophytic vegetation monitoring etc on both the Gnangara and Jandakot mounds) is necessary, given the extent of the area covered by the monitoring program and the nature of scientific and management expertise. As such, it is important to coordinate monitoring of the same GDE components (i.e. wetland vegetation), carried out by different monitoring agencies/individuals across the study area, to ensure the same protocols are adhered to, objectives are met, standards are maintained and reliable information delivered. Consistency within the sampling, analysis, reporting and review across separate monitoring programs will enable information to be easily shared between monitoring and management agencies. This will encourage transparent, critical review of both monitoring and management programs, an
essential component of adaptive wetland (and other GDE) management (Bunn et al. 1997).

4.1 Wetland vegetation monitoring

Pettit (1997) provides a thorough review of monitoring protocols for wetland vegetation on the Swan Coastal Plain. The current wetland vegetation monitoring program largely adheres to these protocols, although limitations associated with monitoring coverage and methodologies have been identified.

Although wetland vegetation monitoring is extensive throughout the Gnangara and Jandakot mounds, a number of specified areas of high ecological value and under threat from predicted drawdown are not included in current monitoring. On the Gnangara mound, wetland vegetation monitoring is largely restricted to criteria wetlands within the Linear wetland chain and Lexia. However, a number of other GDE wetlands within the Linear chain are currently unmonitored despite high ecological values and concern for water levels, namely:

- Loch McNess, Lake Gwelup, Big Carine Swamp, Lake Muckenburra, Bambun Lake, Kings Spring and Quin Brook (see Froend et al. 2004 for ecological values of each wetland).

Specific monitoring of wetland vegetation is also not undertaken at the following high priority wetlands within the Yeal Swamp sub-area, despite terrestrial vegetation transects existing within the area:

- Yeal Swamp, Central Yeal and North-east Yeal (see Froend et al. 2004 for ecological values of each wetland).

Wetlands on the Jandakot mound at which vegetation monitoring is not undertaken despite recognised ecological values include:

- Lake Forrestdale, Mather Reserve, Spectacles North and Harrisdale Swamp (see Froend et al. 2004 for ecological values of each wetland).

With regards to methodological approach, monitoring of wetland vegetation on the Gnangara and Jandakot mounds is mostly adequate, except in circumstances of extreme drought, when more frequent monitoring may be required (Froend and Loomes 2002a).

Groundwater monitoring bores at a number of wetlands at which wetland vegetation monitoring occurs, are not within close proximity (<100m) of the vegetation monitoring transects. Groundwater levels recorded at these bores are therefore not likely to be reflective of the groundwater levels required by the wetland vegetation monitored along the transects. As a result, it is difficult to determine minimum water requirements for the vegetation at these sites, as it is to define relationships between wetland vegetation health and groundwater levels. Wetlands on the Gnangara Mound at which this discrepancy occurs include:

- Lake Yonderup, Lake Joondalup, Lake Jandabup and Dampland 78.

Wetlands on the Jandakot mound at which this discrepancy occurs include:

- Thomsons Lake, North Lake and Lake Kogolup North.
Previous recommendations for a more detailed research program, investigating ecological processes involved in maintaining the fringing vegetation of wetlands, were partly addressed by changes made to the existing monitoring program on the Gnangara mound in 2001 (measurement of elevational ranges of wetland species were made, while transects were altered to include all emergent macrophytes and to exclude plots that did not contain wetland species) (Bertuch et al. 2004). However, recent reports call for a more comprehensive examination of ecological processes that maintain fringing vegetation, as a useful addition to current monitoring program (Bertuch et al. 2004).

4.2 Macroinvertebrate and water quality monitoring

The list of issues given below documents some of the concerns that have been expressed in monitoring reports by consultants over the last 9 years of reporting, plus some other issues that have become apparent during this EWR work.

A substantial database concerning physicochemical aspects of wetlands on the SCP has been accrued over the last 25 years, although most of this data has been descriptive or baseline in nature (Morgan and Davis 1997). Actual monitoring of the physicochemical status of SCP wetlands has commanded less attention and early monitoring programs were conducted in a mostly ad hoc manner, producing ‘data rich but information poor’ results (Morgan and Davis 1997). None of the indicators currently used are set within the context of hypotheses, so strictly speaking we are dealing with a surveillance operation only, capable only of detecting a comparative change. This is valuable but in order to be rigorous about developing an adaptive response capacity for monitoring, capable of detecting an early warning of a specified undesirable change, monitoring programs should be underpinned by hypotheses which incorporate compliance criteria.

The wetlands for which monitoring is required have been specified in Section 46 for the Gnangara Mound, and the Jandakot Groundwater Scheme Stage 2 PER. It is timely to review this list and to either: add wetlands where new environmental values can be ascribed, or where it will increase the analytical power of the monitoring program; or delete wetlands where environmental values previously described have been permanently degraded and no change to this situation is foreseeable. The two critical areas where monitoring is not yet undertaken are:

- Yeal Swamp sub-area: Yeal Swamp, Central Yeal and north-east Yeal (see Froend et al. 2004 for ecological values of each wetland); and
- Swamp systems south of Gingin Brook (see Froend et al. 2004 for ecological values of swamp system).

A review of the wetland values on the Swan Coastal Plain has revealed the priority list of wetlands that have significant macroinvertebrate richness that needs to be protected. This list goes beyond the iconic wetlands that are currently monitored using macroinvertebrates as indicators for change, and while they may simply reflect the sampling and taxonomic effort made at them, are worthy of regular monitoring. These wetlands are:

- Perth Airport Swamps; and
- Twin Swamps.
Rapid bioassessment protocols have been evaluated elsewhere outlining strengths and weaknesses and this report should not re-iterate those. Several other components of the existing procedure are problematic and require comment here.

Linking sampling to habitats is reasonable only so long as the same habitat can be sampled each season at best, or at least each year. Cumulative richness plots at each wetland on the Gnangara Mound have increased each year, suggesting that the sampling cannot completely sample the richness of the habitats, and taxa new to each wetland will continue to be collected. Studies indicate a single, two minute sweep per habitat has been shown to be insufficient to obtain a sample of more than 70% of the families found to be present within a habitat (Sommer and Horwitz, 1998). However, extra sweeps increase sampling times and costs.

The sampling approach used has the benefit of giving a rapid appraisal of richness at a wetland and proportional representation of most littoral invertebrate taxa. The rapid appraisal is a crude (but relevant) measure of water depth (and therefore any change to water regime) because it is correlated with the degree to which littoral vegetation is inundated: greater inundation gives greater habitat complexity, and therefore greater invertebrate richness. The proportional representation of most littoral invertebrate taxa is a crude measure of the influence of other threatening processes such as eutrophication, acidification, salinisation and so on. The assemblage itself has been used to estimate the influence of nutrient or other pollution using indices such as SIGNAL or SWAMPS, most recently adapted by Chessman et al. (2002). Sommer and Horwitz (1998) argued that this latter technique was useful for the detection of eutrophication, but lacked fidelity to detect other forms of pollution and habitat disturbance.

Water quality focuses on physico-chemical attributes of the water column, and bulked water samples analysed for nutrients. With the exception of a few wetlands, the procedure does not incorporate any analysis of biogeochemical indicators. This is a crucial issue given the emergence of acidification as a process relevant to the Swan Coastal Plain, the centrality of wetting and drying cycles of sediment for water quality, and salinisation as a sleeper issue. Water samples at all wetlands should be routinely analysed for sulphate, total iron (both as early warning measures of acidification onset), and calcium (as a measure of buffering capacity).

Studies indicate there is no significant advantage in taking replicate water samples for physico-chemical analyses (Sommer and Horwitz, 1998). However, Sommer and Horwitz (1998) do suggest analysing the water of individual sites rather than using the one bulked sample per wetland (as physico-chemical attributes can vary greatly within a wetland), although note this would increase sampling costs. Very little effort is given to monitor sediments, biogeochemistry or sedimentary processes.

Despite these comments, there is sufficient good long-term data now for a reasonable argument to be made that we have the capacity to understand the significance of changes that we might detect in water quality and littoral macroinvertebrates.

4.3 Phreatophytic terrestrial vegetation

It is difficult to determine existence of clearly defined objectives for monitoring of terrestrial vegetation on the Gnangara and Jandakot mounds, although the absence of a strategic focus is understandable given the early history of the program (Froend and Loomes 2002) (the current monitoring program being developed over the years
through the incorporation of various monitoring programs, each with varying scope and objectives (see Froend et al. 2000 for details). The current annual monitoring reports detail specific objectives which generally refer to the relocation and/or re-pegging of established transects and the establishment of new transects as necessary. Strictly speaking we are dealing with a surveillance operation only, capable only of detecting a comparative change. This is valuable but in order to be rigorous about developing an adaptive response capacity for monitoring, capable of detecting an early warning of a specified undesirable change, monitoring programs should be underpinned by hypotheses which incorporate compliance criteria.

Although the techniques used to describe vegetation condition are thorough, there are some concerns regarding the monitoring of terrestrial vegetation. For instance, consistency in understorey scoring and strategic values of each transect and whether or not the location and number of sites meet monitoring objectives, is of concern, particularly the fact groundwater levels are not recorded at the monitoring transects, making comparisons between vegetation changes and hydrology difficult (Froend and Loomes 2002). In some cases bores are monitored within terrestrial sites that have been severely altered (e.g. vegetation bulldozed) and such drastic changes have gone unreported in a few instances as groundwater levels were the only parameter measured and recorded, and these levels alone do not reflect the condition of terrestrial vegetation. Such scenarios provide prime examples of the necessity to ensure correlations exists between monitoring bores and transect locations and for parameters, other than groundwater levels alone, to be included as criteria within a monitoring program for phreatophytic terrestrial vegetation.

Froend and Loomes (2002) identify a number of areas on the Gnangara mound not included in current monitoring programs, despite being at great risk of impact from declining groundwater levels. The areas of terrestrial vegetation of high conservation value, in areas of shallow and moderate depth to groundwater that have experienced drawdown, are predicted to undergo further groundwater declines and are currently not monitored include:

- Central Yeal, North Muchea and PM4 sub-areas (see Froend et al. 2004 for ecological values of each wetland).

Soil moisture measurements have been inconsistently measured at transects and cannot be correctly interpreted without greater frequency of sampling (Froend and Loomes 2002). Soil moisture conditions vary significantly on the mound from area to area depending on rainfall, types of soils and plant communities, differences in local recharge and transpiration rates, differences in local land uses and differences in relation to proximity of water extraction bores (Mattiske 2001). However, although numerous factors influence soil moisture aside from groundwater levels, this parameter is useful as an indicator of groundwater drawdown and its influence on phreatophytic vegetation, providing physical and biotic characteristics are allowed for and monitoring is frequent and continuous.

Mattiske (2003) recorded decreases in a number of short-lived understorey species at monitoring transects on the Gnangara mound. In some cases, the time since the last fire and the life span of a given species appear as critical as underlying soil moisture and site conditions when assessing the condition of a population (Mattiske 2003). As such, a review of the fire regimes at some transects on the Gnangara mound is called for before factors leading to the decline of short-lived seeder perennial species can be confidently stated (Mattiske 2003).
A major consideration when assessing the vigour of plant species and communities is the presence of root fungi (Phytophthora species) which causes dieback in many native species dominant on the SCP (Mattiske 2001). Although monitoring of terrestrial vegetation on the Jandakot mound has not recorded the presence of this fungus, it is important to keep in mind when interpreting monitoring results as it can result in pockets of dead and dying trees and understorey species (Mattiske 2001). Banksia attenuata, common to the SCP, is found on mid to upper slopes and is prone to the effects of Phytophthora (Mattiske 2003). Monitoring of terrestrial vegetation of the Gnangara mound recorded reduced vigour and patches of dying B. attenuata at Whiteman Park, Yanchep and Yeal transects (Mattiske 2003). Mattiske (2003) note there is no doubt that drought conditions and below average rainfall are the main determinants of the decline, however it is also noted that further research is required before the possibility of the presence of Phytophthora leading to the decline of B. attenuata can be discounted.

### 4.4 Threatened Ecological Communities

A number of groundwater dependent TECs have been identified on the SCP, including tumulus springs (otherwise known as ‘organic mound’ springs), aquatic root mat communities, deeper sandy wetlands of sandy soils, sedgelands in halocene dunes swales of the southern SCP, herb rich saline shrublands in claypans, forest and woodlands of deep seasonal wetlands of the SCP, Perth to Gingin Ironstone Community, Herb rich shrublands in claypans, Eucalyptus (Corymbia) calophylla – Xanthorrhoea preissii woodlands and shrublands SCP, shrublands on calcareous silts of the SCP, Banksia attenuata woodland over species rich dense shrubland and shrublands on dry clay flats. While the occurrences of the first two on the Gnangara Mound are regularly monitored, occurrences of the latter ten are not monitored, namely:

- Deeper sandy wetlands of sandy soils: occur within Central Yeal sub-area (wetland 195-MILT05) and Ridges sub-area (wetland 444-YAN21).
- Sedgelands in halocene dunes swales of the southern SCP: occur within Wanneroo Linear Wetlands west of Lake Wilgarup and north of Pipidinny Swamp (XYAN10).
- Herb rich saline shrublands in claypans: occur in a number of locations including sites around sites around Lake Bambun (GINGIN 01, 02, 03; BAMBUN 01, 03), Bullsbrook (BULL 06, BULL 08) and to the north of the study area at Lake Muckenburra (MUCK 02) and is listed as vulnerable.
- Forest and woodlands of deep seasonal wetlands of the SCP: occur at Lake Bambun (BAMBUN 02) north of Yeal Nature Reserve and north-east of Lexia (TWIN05, TWIN10). This TEC has been listed as vulnerable.
- Perth to Gingin Ironstone Community: this critically endangered TEC occurs on land adjacent to the Gingin airfield (NIRONSE, NIRONSE2, NIRONSW, NIRONNW, NIRON02, NIRON03).
- Herb rich shrublands in claypans: Five occurrences of this vulnerable TEC occur east of Bullsbrook (ELLEN 01, ELLEN 02, ELLEN 03, ELLEN 04, ELLEN 05).
- **Eucalyptus (Corymbia) calophylla** – *Xanthorrhoea preissii* woodlands and shrublands, SCP: occur east of Bullsbrook (PEARCE 02) and in Ellenbrook (ELLEN 06). This TEC is listed as endangered.

- Shrublands on calcareous silts of the SCP: this vulnerable community type is founding the Ellenbrook area east of Lexia (VINESSE).

- **Banksia attenuata** woodland over species rich dense shrubland: occur within the Gnangara Road Bushland (Telstra01-08), Decourcey Road Bushland (GOLF01-03), Landsdale Road Bushland (LAND01), Errina Road Bushland (ERRINA01-05). This TEC is listed as endangered.

- Shrublands on dry clay flats: occurrences of this endangered TEC occur include Forrestdale Lake and adjacent bushland, Anstey/Keane dampland and adjacent bushland and Nicholson Road bushland.

Although monitoring of TECs such as tumulus springs and aquatic root mat communities of cave streams has intensified in recent years due to high risks posed by groundwater drawdown, the absence of a regular monitoring program for the remaining TECs listed above is an issue of concern (Froend *et al.* 2002).

### 4.4.1 Aquatic root mat communities of cave streams

Current hydrological conditions of the seventy-one caves identified within the Yanchep area, known to have contained water at some stage in the past, have been documented by Lex Bastian, a local speleologist of immense experience (Knott and Storey 2004). Of these, 16 caves had an ‘unknown’ status, meaning they had not been entered in the last 10 years. Knott and Storey (2004) recommend these caves be revisited as soon as possible to determine their current hydrological regime:

- Cave YN59, Cave YN86, Cave YN110, Cave YN151, Cave YN197, Cave YN203, Keyhole Cave (YN217), Cave YN233, Cave YN254, Cave YN289, Cave YN298, Cave YN362, Cave YN371, Cave YN397, Goalpost Cave (YN403) and Cave YN465 (although this cave may not be accessible).

### 4.4.2 Tumulus Springs

Kings Spring, a tumulus mound spring located northwest of Bullsbrook, is not currently monitored despite supporting a TEC (as based on vegetation and invertebrates). Jasinska and Knott (1994) surveyed a number of springs on the Gnangara Mound which were upstream of the proposed Lexia wellfield. None of these wetlands were selected for monitoring/conservation-setting EWRs even though they contained restricted and endemic invertebrate fauna. These sites all now lie within the greater study area, but have not been sampled/monitored since 1994 and their current status is unknown.

Water quality and macroinvertebrate monitoring is undertaken at Egerton Spring, as outlined in Section 3.4.2, however vegetation monitoring is not carried out at this spring.

The measurement of discharge rates for tumulus springs, enabling meaningful comparisons between monitoring events, requires further investigation in order to develop a satisfactory methodology (Horwitz and Knott 2003). In 2002 a small weir was planned for installation on Egerton Spring to measure runnel discharge, although to date this has not been installed.
4.5 Frogs, reptiles, landbirds and mammals and waterbirds

4.5.1 Frogs

The timing of frog trapping at Lexia 86 and EPP Wetland 173 (see Section 3.5.1) during 2003 was such that winter breeding species such as *Crinea spp.*, were past their breeding peak and as a result numbers of these species have probably been under-estimated (Bamford and Bamford 2003). This may also explain low capture rates for other frog species at these wetlands (Bamford and Bamford 2003).

Low numbers of *H. eyrei* breeding females captured at EPP Wetland 173 surprised Bamford and Bamford (2003), particularly as the timing of trapping coincided with the breeding period of this species (i.e. autumn). It was suggested the low numbers may reflect a difference of a few days in the timing of female migration at the two monitored wetlands, or may be due to the positioning of traps along the migration routes, hydroperiod differences or a demographic problem (Bamford and Bamford 2003). Further monitoring is called for to help clarify these questions.

Tadpole sampling was well timed to detect the presence of well-developed larvae of autumn breeding species. Bamford and Bamford (2003) suggest further sampling events during November could be undertaken in order to detect the presence of species that have not finished breeding by autumn.

4.5.2 Waterbirds

Total waterbird species counts are not possible where dense wetland vegetation restricts access and visibility and are also not possible for cryptic species such as some crakes and rails, the Clamorous Reed-Warbler and the Little Grassbird (Bamford and Bamford 2002). This limitation is an issue at The Spectacles.

4.6 Surface water and groundwater levels

The current network of monitoring bores and staffs has been established over the last 35 years in response to a number of different management programs with varying objectives and requirements. As a result, monitoring bores and measuring staffs are not of uniform standard and are in some cases inappropriately located and constructed (Rockwater 2003). Groundwater levels monitored in such bores do not accurately reflect surface water levels of the relevant wetlands.

In a review of the surface water and groundwater monitoring for wetlands on the Gnangara and Jandakot Mounds, Rockwater (2003) found 23 (74%) of 31 wetlands had either no criteria bores, the criteria bores were unsuitable (inappropriately located) or provided no/insufficient groundwater and/or surface water data. Furthermore, Rockwater (2003) state that without more detailed investigation it is very difficult to locate groundwater monitoring bores which will accurately reflect surface water levels in wetlands.

Groundwater levels which are monitored at bores not within close proximity (<100m) of vegetation monitoring transects are not likely to be reflective of the groundwater levels required by the wetland vegetation monitored along the transects. Wetlands at which this occurs and where the location of monitoring bores needs to be reconsidered include:

- Lake Yonderup
- Lake Joondalup
- Lake Jandabup
- Dampland 78
- Thomsons Lake
- North Lake
- Lake Kogolup North

Discrepancies between data obtained from monitoring bores and wetland water levels have been identified at Melaleuca Park EPP 173, where differences exist between water levels measured at staff gauges and monitoring bores at this wetland. This may lead to inaccurate readings following the drying of a wetland and a change from the recording of surface water levels to groundwater depths (Loomes and Froend 2001c). The accuracy of setting and monitoring water level criteria may be seriously compromised when considering breaches of water level criteria can vary in duration and severity depending on which data set is considered (Loomes and Froend 2001c).

The frequency of surface water and groundwater level monitoring at criteria wetlands is generally considered adequate although in some areas frequency may not be suitable to accurately describe drawdown patterns (Froend and Loomes 2002). The monitoring bore at Bibra Lake has not been monitored since 1999, despite being identified as entirely groundwater dependent (Rockwater 2003) and having habitat diversity and waterbird refuge values.

Aquaterra (2004) review groundwater monitoring on the SCP between the Gnangara and Jandakot mounds, in one of several reports commissioned by WRC to fulfil the requirements of the Section 46 review. Assessment of the extent and condition of the current network and recommended changes are detailed by Aquaterra (2004) and will not be repeated here. However, a summary of Aquaterra’s (2004) recommendations with regards to the frequency and areas for future monitoring is provided in Section 5.6.

### 5.0 MONITORING RECOMMENDATIONS

Wetland monitoring is defined as the collection of specific information for management purposes in response to hypotheses derived from assessment activities, and the use of these results for implementing management (Finlayson 2003). This definition can be equally applied to the monitoring of other GDEs components, such as phreatophytic vegetation or TECs. Monitoring is differentiated from inventory (the collection of information to describe the ecological character of an ecosystem, such as wetlands), and from assessment (which identifies the pressures and associated risk of adverse change in the ecological character of given ecosystem) (Finlayson 2003).

A number of reasons for the implementation of a monitoring program have been identified and include: to characterise variations in responses of ecosystems to natural variability in the environment; to collect baseline data on an ecosystem as part of the inventory process; to record ecological changes occurring as result of specific natural or anthropological events; to measure progress towards set objectives of a management program and; to audit performance of management agencies and land users (Bunn et al. 1997; Finlayson and Mitchell 1999). All of the above reasons,
particularly the latter three, are relevant to the monitoring of GDEs on the Gnangara and Jandakot mounds.

Finlayson and Mitchell (1999) present a protocol for the monitoring of Australian wetlands adapted from monitoring protocols developed by Bunn et al. (1997) (in turn based in part on protocols developed by the Ramsar Convention on Wetlands of International Importance (see Finlayson 1996)). The protocol involves a logical series of steps with feedback loops to encourage adaptive management and at the same time assists researchers to gain information and refine knowledge about ecosystems (Finlayson 1999). The steps are as follows:

- **Objectives**: explicitly and clearly stated in terms that permit them to be quantitatively assessed.
- **Management expectations**: described in terms that will allow them to be measured for duration of monitoring program.
- **Assumptions**: the reasons behind management expectations must be clearly identified and stated in form of hypotheses that can be tested in an appropriately designed monitoring program.
- **Gaps in knowledge or uncertainties**: expressed as well focused hypotheses that can be tested in monitoring program or formulated as research projects that run parallel to monitoring program.
- **Performance criteria**: stated for each expectation of the management program in terms that can be measured and assessed.
- **Feasibility and cost effectiveness**: methods tested and costs within budget.
- **Sampling methods**: clearly described and tested before the monitoring program commences to ensure results will be statistically valid in terms of frequency of sampling and replication.
- **Analysis of samples**: detailed methods established and set in place to ensure expeditious processing of samples and reporting of results.
- **Reporting of results**: procedures established to expedite reporting to all interested parties.
- **Critical review**: procedures established to review sampling and analysis and where appropriate adjust/terminate program.

The formulation of a testable hypothesis is critical to the effectiveness of a monitoring program. Finlayson and Mitchell (1999) explain that monitoring is underpinned by the assumption that there is a specific reason for the collection of data, and the assumption should be clearly stated and presented as a hypothesis, subsequently tested and the information assessed and fed back into the management process. Management performance and accountability are also critical to effective monitoring and should be monitored alongside ecological parameters (Finlayson and Mitchell 1999). An iterative relationship between monitoring and management should exist, resulting in an adaptive wetland management program, where monitoring data provides a check on the progress of management and if necessary, the management program can be amended to ensure objectives are being met (Bunn et al. 1997). A strong relationship between monitoring and research should also be encouraged in order to refine and extend scientific knowledge of the ecosystem (Bunn et al. 1997). Morgan and Davis
(1997) recommend collection of several different types of data sets to allow multiple assessments of the ecological status of wetlands, as well as providing an insight into relationships between physicochemical attributes and ecological functions, a recommendation equally applicable to other GDE monitoring. Bunn et al. (1997) suggest entire monitoring programs should be critically reviewed at least annually.

Finlayson and Mitchell (1999) comment that wetland monitoring within Australia is plagued by attitudes that have undervalued the role of monitoring as a critical component of wetland management. They call for rigorous scientific principles and practice to be applied to the planning and implementation of monitoring programs, and the long-term commitment of resources to achieve goals (Finlayson and Mitchell 1999).

System level recommendations

Throughout the review process it became apparent that a number of the limitations and subsequent recommendations identified within the monitoring programs were applicable at a higher system or overarching level (a level at which the monitoring and management of GDE components is holistically approached). It also became apparent that despite the importance of a coherent and holistic monitoring approach (see Section 4 for details), this is lacking from the current monitoring of GDEs on the SCP. In response, a number of recommendations have been put forward to encourage development of overarching/system level monitoring approach.

The critical importance of monitoring objectives, stated as clear and testable hypotheses, to the effectiveness of a monitoring program, has been emphasised by number of authors (see Bunn et al. 1997; Finlayson (2003); Finlayson and Mitchell (1999)). The current program lacks clear identification and definition of monitoring objectives and assessment criteria at the higher system or overarching level. In order to address this issue the project team suggest the following system level objectives for the monitoring of GDEs on the Gnangara and Jandakot mounds:

1. to forecast system level response to a changing groundwater/surface water regime;
2. to ensure an early-warning system for critical GDE components; and
3. to improve understating of GDE response to a changing groundwater/surface water regime (keeping in mind there may be unforeseen indicators of GDE response to changing groundwater regimes, currently unmonitored).

These objectives were recommended in response to the criticism that there is currently no forecasting of declining groundwater levels and the subsequent impacts on GDEs, built into the monitoring program. At present, groundwater levels are the only criteria which, when breached, trigger a management response (namely the switching off of groundwater abstraction bores where appropriate). As previously outlined (see Section 2.6), although the monitoring of groundwater levels provides the best ‘early warning’ capability of the potential impacts of changing groundwater levels on ecosystem health, this parameter is only useful if we know how the ecosystem attributes and values respond to changes in groundwater levels, an area still in need of further research.

Suggestions for system level criteria that may be used to forecast a changing groundwater/surface water regime include:

- rainfall falling below the long-term average;
• proportion of surface water on the SCP (excluding areas of perched surface water) falling below the long-term average;
• proportion of rechargeable rainfall (taking into account the proportion of land on which recharge can occur and the rate of recharge) falling below the long-term average.

Specific criticisms have also been made with regards to the lack of clearly identifiable objectives within the wetland vegetation, macroinvertebrate and water quality and phreatophytic vegetation monitoring programs. It is recommended that for each GDE component and relevant monitoring program, clear identification and definition of monitoring objectives be developed and expressed and testable hypotheses. These hypotheses should relate the loss of environmental values of a specific GDE to the groundwater regime and should incorporate monitoring parameters as compliance criteria. For instance, if a wetland has diverse littoral and fringing vegetation in good condition, supporting a diverse macroinvertebrate community and providing habitat for water birds, an appropriate hypothesis may be:

*Increasing depth to groundwater will lead to a change in the structure, condition and vigour of littoral and fringing vegetation resulting in the decline of habitat values.*

The ‘change in structure, condition and vigour’ can be measured using the parameters outlined in Section 2.1 (i.e. species diversity, species cover and abundance, vegetation structure, community distribution etc.). However, what constitutes a ‘change’ resulting in a loss of values will depend on the current condition of the littoral and fringing vegetation which led to the assignment of habitat values. Similarly, at a wetland where representativeness values have been assigned based on an unusual hydrologic regime (e.g. extremely high turbidity), which subsequently supports a unique assemblage of aquatic macroinvertebrates, it would be necessary to devise a different set of compliance criteria based on water quality parameters (see Section 2.2), than at a wetland where water quality parameters naturally fall within a more common range. The setting of compliance criteria indicative of a change within a monitored parameter that may lead to the loss of environmental values, will be dependent on the current condition of a given GDE component (i.e. a specific wetland or distinct community of phreatophytic vegetation) that has led to the assignment of environment values to that component.

A number of recommendations have been made to include and/or exclude additional sites within the monitoring programs for each GDE component. The project team recommend the following overarching rationale guide the selection of monitoring sites:

• all GDE classes are included and well represented;
• areas of high conservation and under high risk are included;
• sites at which existing monitoring occurs but at which values have been lost (and are unlikely to be recovered) are removed; and
• monitoring data from each site collectively contribute to the understanding of GDE response to changing groundwater/surface water regimes.
Recommendations specific to the monitoring of each GDE component within the study area are detailed in the following sections.

5.1 Wetland vegetation monitoring

Recommended changes and additions to the existing wetland vegetation monitoring programs on the Gnangara and Jandakot mounds include:

- The clear identification and definition of monitoring objectives, incorporating compliance criteria and expressed as testable hypotheses.

- Expansion of current vegetation monitoring to include the following wetlands identified as high priority (high conservation values and/or greatest risk of impact from historic and predicted drawdown):
  - Linear wetlands – Loch McNess (supports range of habitats and includes priority flora, unusual hydrologic regime, excellent water quality, rich aquatic fauna and acts as a drought refuge)
  - Central Yeal – wetlands 161, 188, 221, 276
  - Yeal Swamp – Lake Bindiar, Yeal Swamp and wetlands 137, 181, 193 (key faunal habitats and representative of terrestrial vegetation)
  - North-east Yeal – wetlands 231, 234, 235
  - Pinjar (north/south) – Lake Pinjar (Bush Forever site 382) (Note: although water levels are predicted to increase at Lake Pinjar, the high conservation value of the remnant Pinjar vegetation complex and significant historic drawdown (see Froend, Loomes and Zencich 2002) may justify monitoring at this site).

- Expansion of current vegetation monitoring to include the following wetlands at which ecological values are recognised:
  - Lake Gwelup (supports waterbird species and other dependent vertebrates)
  - Big Carine Swamp (supports waterbird species and other dependent vertebrates)
  - Lake Muckenburra (supports waterbird species, other dependent vertebrates and TEC)
  - Bambun Lake (supports diverse fish species, other dependent vertebrates and TEC and provides fauna habitat)
  - Kings Spring (supports TEC)
  - Quin Brook
  - Lake Forrestdale (bushland surrounding the wetland supports declared rare and priority flora)
  - Mather Reserve (supports non-aquatic fauna and waterbirds)
  - Spectacles North (supports aquatic and non-aquatic vertebrates and vegetation provides a range of habitats)
  - Harrisdale Swamp (supports non-aquatic invertebrates)
• Groundwater monitoring bores need to be re-located at the following wetlands to ensure they are within close proximity (<100m) of wetland vegetation monitoring transects:
  – Lake Yonderup
  – Lake Joondalup
  – Lake Jandabup
  – Dampland 78
  – Thomsons Lake
  – North Lake
  – Lake Kogolup North

• Setting of criteria that are indicative of periods of extreme drought and if breached trigger more frequent (i.e. monthly) monitoring of wetland vegetation.

With regards to the last recommendation, the current drought response trigger is water storage in dams falling below 100GL or when inflow to dams through winter is insufficient to avoid the possibility of such low levels through the following summer period (Welker Environmental Consultancy 2002). This trigger has been developed as part of a Drought Emergency Response Plan to ensure essential in-house water and industrial needs of the Integrated Water Supply System are met under emergency conditions. This may not be a suitable trigger to indicate periods of extreme drought and the subsequent implications for wetland vegetation and other GDEs. System level criteria indicative of periods of extreme drought need to be developed within the context of GDE management, for instance, a winter rainfall that falls below the long-term average could be used as a trigger for more frequent monitoring.

Bunn et al. (1997) recommend encouraging strong relationships between monitoring and research activities, in order to refine and extend scientific knowledge of the ecosystem. An opportunity exists to strengthen the relationship between monitoring and research within the current monitoring program through the initiation of a comprehensive examination of ecological processes that maintain fringing wetland vegetation (recommended by Bertuch et al. (1997)).

5.2 Macroinvertebrate and water quality monitoring

The principal purpose of the macroinvertebrate monitoring programme has always been to devise a measurement protocol with the ability to detect any change to the water regime that results in undesirable consequences for water quality and or macroinvertebrate assemblages. The monitoring should therefore be capable of detecting not just the direct effects of changed water regime, but also those impacts that are mediated by another form of human disturbance. For instance, water borne pollutants might only become relevant under a particular water regime, or excessive nutrients only problematic during particularly low water levels, and so on.

Recommended changes and additions to the existing macroinvertebrate and water quality monitoring programs on the Gnangara and Jandakot mounds include:

• The clear identification and definition of monitoring objectives, incorporating compliance criteria and expressed as testable hypotheses.
• Addition of wetlands to the monitoring program that have significant macroinvertebrate values, namely:
  – Yeal Swamp wetlands: Yeal Swamp, Central Yeal and North-east Yeal;
  – Swamp systems south of Gingin Brook;
  – Perth Airport Swamps; and
  – Twin Swamps.

The latter two wetlands may be used as external controls for either the Jandakot or the Gnangara Mound wetlands of interest.

• Coogee Springs and Lake Wilgarup could be removed from the monitoring program if previous environmental values are not re-established, given the loss of critical diversity of aquatic fauna and habitat values at these wetlands (see Froend et al. 1994).

• Ensure that sampling occurs twice per year, and to link sampling not to seasons but to wetting and drying cycles; the ‘first flush’ of water into wetlands at start of winter rains must be sampled to provide valuable information on nutrient loading into wetlands (Morgan and Davis 1997).

• Consider adding a benthic invertebrate sampling program, particularly for the indicator group Oligochaeta, to invertebrate monitoring protocols.

• Having stressed the importance of identifying invertebrate previously sampled to the lowest taxonomic level in order to determine the presence of rare taxa which may be threatened by continued declines of water level and quality, Benier and Horwitz (2003) suggest starting immediately with high priority wetlands where habitat loss is evident, those being:
  – Lake Mariginiup
  – Nowergup Lake
  – Melaleuca Park EPP 173
  – Lake Wilgarup
  – Coogee Spring
  – Lexia 86
  – Lexia 186.

A nine year dataset has been established for both mounds and a refined taxonomic treatment of macroinvertebrate collections for both mounds should reveal the true extent of endemism or rarity in wetlands on the Swan Coastal Plain (see Horwitz et al. in prep).

• Design a sediment monitoring process capable of detecting changes to dominant biogeochemical processes, for key indicator wetlands.

• Consider introducing the analysis of analysis of sulphate and total iron (as early warning measures of acidification onset) and calcium (as a measure of buffering capacity) to water quality analysis for each wetland.

Frequency of monitoring sampling should be sufficient to cover seasonal variation. It has been argued (Morgan and Davis 1997) that six monthly sampling of physico-
chemical parameters is barely adequate to encompass climatic variation on the Swan Coastal Plain. Morgan and Davis (1997) recommended:

- Sampling should ideally be at intervals of two months or less, and that ‘first flush’ of water into wetlands at start of winter rains must be sampled to provide valuable information on nutrient loading into wetlands. Presumably this would give insights into other forms of loadings and into water quality effects of the drying and re-wetting cycle as well.

On many occasions over the last nine years wetlands have not been sampled due to there being insufficient surface water. This usually was the case for summer sampling, but occasionally occurred in spring sampling. This situation is exacerbated during years of extreme drought. The best option here is to ensure that sampling occurs twice per year, and to link sampling not to seasons but to wetting and drying cycles. Clark and Horwitz (2004) stated the situation as follows:

> For some ephemeral systems, particularly since surface waters have declined on the Gnangara Mound, the period of time between filling and thereby showing surface waters, and drying completely, can be rather short. For instance a wetland like Lexia 186 might only have surface water for 2 months over late spring and early summer. Macroinvertebrate fauna therefore emerge/colonise, persist and breed during this time. Where the duration of surface water is short, the options for sampling fauna are limited – not too early because some components of the fauna may not have emerged or colonised yet, and not too late in the drying phase because there may be insufficient water to sample. In previous rounds this problem was circumvented by sampling only once, at the height of the water. For Rounds 16 and 17, where this situation was encountered, two samples were taken, one on each shoulder of the season.

### 5.3 Phreatophytic vegetation monitoring

Recommended changes and additions to the existing phreatophytic terrestrial vegetation monitoring program on the Gnangara and Jandakot mounds include:

- The clear identification and definition of monitoring objectives, incorporating compliance criteria and expressed as testable hypotheses.

- Expansion of current monitoring program to include transects incorporating the following areas of high priority terrestrial vegetation (see Loomes and Froend 2002):
  - Central Yeal;
  - PM4 (Muchea); and
  - North Muchea.

- Establish hydrological monitoring at existing and additional sites to include at least one monitoring bore near the mid-point of monitoring transects (Loomes and Froend 2002). It should also be ensured that correlations exist between monitoring bores and transect locations.
• Monitoring of transects to occur at regular, three year periods (Mattiske 2001). Consistent understorey scoring and strategic values of each transect also needs to be ensured.

• Groundwater monitoring bores located within close proximity to stands of native phreatophytic vegetation should be constantly checked for compliance with pre-determined environmental water provisions (EWP's), particularly during years of poor recharge (Groom et al. 2000). If monitoring indicates water levels are likely to breach pre-determined EWP's, the frequency of groundwater monitoring needs to be increased (Groom et al. 2000).

• Further investigation of different fire regimes on species and communities is required and review of fire regimes at monitoring sites should be undertaken in consultation with land managers and Department of Conservation and Land Management (CALM) staff (Mattiske 2003).

• Contact with local land managers (particularly CALM staff) should be maintained in order to minimise disturbance to monitoring transects (including pressures from activities which may be carried out in areas adjacent to the monitoring locations (i.e. quarry activities)) (Mattiske 2003).

As previously mentioned, strong relationships between monitoring and research activities are encouraged in order to refine and extend scientific knowledge of the ecosystem (Bunn et al. 1997). Calls for additional research have been made in order to determine the groundwater drawdown tolerance thresholds of the drought sensitive Holly-leaf Banksia (*Banksia ilicifolia*) at various depths to groundwater, in order to further understand the significance and potential impacts of declining groundwater levels on this species (Groom et al. 2000). There is also an opportunity for further research to determine if the presence of the root fungi *Phytophthora* may be contributing to the decline of *Banksia attenuata* at Whiteman Park, Yanchep and Yeal transects (Mattiske 2003).

If the precautionary principle is to guide monitoring and management activities, trends observed in relation to management should be extrapolated in the context of changing seasonal conditions, pumping regimes, land uses, areas of native vegetation and fire regimes (Mattiske 2001). The implications of research activities and monitoring reports needs to be reviewed in collaboration with officers of the Department of the Environment, CALM and Water Corporation (Mattiske 2003). Groom et al. (2000) suggest in a worst case scenario, where water levels are likely to breach EWP's, pumping from local production wells should cease until sufficient groundwater recharge occurs.

### 5.4 Threatened Ecological Community Monitoring

The following ten, currently unmonitored, groundwater dependent TECs identified on the SCP, should be included within future monitoring of TECs:

- Deeper sandy wetlands of sandy soils: occur within Central Yeal sub-area (wetland 195-MILT05) and Ridges sub-area (wetland 444-YAN21).

- Sedge lands in halocene dune swales of the southern SCP: occur within Wanneroo Linear Wetlands west of Lake Wilgarup and north of Pipidinny Swamp (XYAN10).
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- Herb rich saline shrublands in claypans: occur in a number of locations including sites around Lake Bambun (GINGIN 01, 02, 03; BAMBUN 01, 03), Bullsbrook (BULL 06, BULL 08) and to the north of the study area at Lake Muckenburra (MUCK 02) and is listed as vulnerable.

- Forest and woodlands of deep seasonal wetlands of the SCP: occur at Lake Bambun (BAMBUN 02) north of Yeal Nature Reserve and north-east of Lexia (TWIN05, TWIN10). This TEC has been listed as vulnerable.

- Perth to Gingin Ironstone Community: this critically endangered TEC occurs on land adjacent to the Gingin airfield (NIRONSE, NIRONSE2, NIRONSW, NIRONNW, NIRON02, NIRON03).

- Herb rich shrublands in claypans: Five occurrences of this vulnerable TEC occur east of Bullsbrook (ELLEN 01, ELLEN 02, ELLEN 03, ELLEN 04, ELLEN 05).

- *Eucalyptus* (Corymbia) calophylla – *Xanthorrhoea preissii* woodlands and shrublands, SCP: occur east of Bullsbrook (PEARCE 02) and in Ellenbrook (ELLEN 06). This TEC is listed as endangered.

- Shrublands on calcareous silts of the SCP: this vulnerable community type is found in the Ellenbrook area east of Lexia (VINESSE).

- *Banksia attenuata* woodland over species rich dense shrubland: occur within the Gnangara Road Bushland (Telstra01-08), Decourcey Road Bushland (GOLF01-03), Landsdale Road Bushland (LAND01), Errina Road Bushland (ERRINA01-05). This TEC is listed as endangered.

- Shrublands on dry clay flats: occurrences of this endangered TEC occur include Forrestdale Lake and adjacent bushland, Anstey/Keane dampland and adjacent bushland and Nicholson Road bushland.

### 5.4.1 Cave stream communities

Caves of the Yanchep area contain a high diversity of aquatic fauna relative to other cave systems around the world, with a high level of endemism over a short distance; adjacent underground streams contain different genera of endemic amphipods suggesting in situ speciation with little lateral movement. This indicates a high potential for the area and Gnangara Mound in general to contain many more species of endemic stygofauna. A detailed survey of the whole Gnangara mound for stygofauna should be conducted as soon as possible. Methodology should be based on the recommendations of the EPA for stygofauna monitoring, those being repeated hauls with conical plankton nets of 150μm and 50μm mesh aperture, with net diameter being slightly smaller than bore internal diameter. Objectives are to determine the presence of stygofauna, and establish taxonomic relationships to known stygofauna and cavernicole fauna of the area/region.

Over the last decade, 16 caves on the SCP have remained unentered and the status of their hydrological condition subsequently remain ‘unknown’ (Knott and Storey 2004). Knott and Storey (2004) recommend these caves be revisited as soon as possible to determine their current hydrological regime:

- Cave YN59
- Cave YN86
Cave YN110
Cave YN151
Cave YN197
Cave YN203
Keyhole Cave (YN217)
Cave YN233
Cave YN254
Cave YN289
Cave YN298
Cave YN362
Cave YN371
Cave YN397
Goalpost Cave (YN403)
Cave YN465 (although this cave may not be accessible).

Other recommended changes and additions to the existing monitoring program for aquatic root mat communities in cave streams on the Gnangara mound include:

- Monitoring of cave stream fauna should take place in September/October, when habitat area is likely to be greatest, in order to assess recovery of fauna should it occur (Knott and Storey 2003).
- Boomerang Cave, unmonitored in 2003 as it had dried out due to maintenance issues with the recharge system, should be included in future monitoring to determine if the TEC has been subsequently lost at this site (Knott and Storey 2004).
- In addition to fauna monitoring, the condition of the Tuart root mats in the caves, which provide habitat and food for the fauna is important. Photo points should be used to monitor the condition of selected root mats, specifically the areal coverage of root mats and the presence of active new growth.

In recent years groundwater levels have fallen below the floor of most caves and the caves have dried in summer, with some also remaining dry during winter. Artificial supplementation from sumps in the floor of the caves is about to be replaced by artificial recharge of the local aquifer from a dedicated groundwater production bore. In principal, this will re-flood the caves, enhance root mat growth and allow the return of the fauna from any refuge populations still remaining in the system. Fauna monitoring should continue to record any recovery.

5.4.2 Tumulus mound springs

A number of tumulus mound springs, previously found to contain restricted and endemic invertebrate fauna, have not been considered for ongoing monitoring as they were outside initial study areas (Jasinska and Knott 1994). The current status of these springs is currently unknown as sampling has not occurred since 1994. It is recommended the current status of the following sites (located within the Ellenbrook Centre for Ecosystem Management, ECU, Joondalup
area on the Gnangara mound – see Jasinska and Knott (1994) for location details of numbered sites) be determined as soon as possible and any sites found to contain extant fauna be included in routine annual monitoring:

- Site 3 swamp (3s), Bullsbrook
- Site 3 road (3r), Bullsbrook
- Site 3 bush (3b), Bullsbrook
- Site 4 nursery (4), Bullsbrook
- Site 5 spring (5s), Muchea
- Site 5 dam (5D), Muchea
- Site 5 piezometer spring (5ps), Muchea
- Site 5 piezometer dam (5pD), Muchea
- Site 7 runnel (7), Bullsbrook
- Kings Spring.

Other recommended changes and additions to the existing monitoring program for tumulus mound springs on the Gnangara mound include:

- Monitoring of the aquatic fauna at Egerton Spring to include specific searches for gilgies, as they were not recorded during 2002 surveys despite the probability they still exist on the spring mound (given relatively favourable habitat conditions i.e. the spring did not dry out during summer 2001/2002) (Horwitz and Knott 2003).
- The preparation of a ‘user friendly’ voucher and identification key of the taxonomic traits of each species occurring on Egerton Spring is recommended as a high priority (Horwitz and Knott 2003).
- In October 2002 it was proposed to install a small weir on Egerton Spring in order to measure runnel discharge, although to date this has not been installed. Horwitz and Knott (2003) recommend monitoring runnel discharge monthly from October through to the commencement of rains the following year. Regularly monitoring during the dry summer period is important to enable rapid response should discharge rates drop substantially (Horwitz and Knott 2003).
- Although the usefulness of monitoring Edgecombe Spring is questioned given the decreasing faunal diversity and no sign of improvement, continued monitoring is recommended for at least two more years to determine whether or not there is a substantial return of fauna, after which the usefulness of this monitoring program should be assessed (Horwitz and Knott 2003).

5.5 Frog, reptile, landbird and mammal and waterbird monitoring

5.5.1 Frogs

The results of the most recent monitoring by Bamford and Bamford (2003) are considered suitable baseline data against which future monitoring results can be compared. Recommendations for future surveys include:
• Focusing future tadpole trap calibrations at Lexia 86, a smaller, shallower and warmer than EPP Wetland 173, as future changes will be easier to detect given relatively high tadpole densities (Bamford and Bamford 2003).

• Pitfall trapping to detect breeding success of adult frogs (particularly *H. eyrie*) and recruitment success as measured by captures of metamorphs.

• Tadpole trapping at both wetlands to monitor recruitment of larvae into the population. Tadpole trap calibrations should be undertaken at the Lexia 86 wetland during 2004 to increase sample sizes available for analysis.

• Tadpole trapping should be carried out slightly later in the year than was possible in 2003 to detect species that breed late in spring.

• Censuses of calling males to enable comparisons of densities between years could be repeated more often and preferably in a few seasons such as July and November. This will allow greater resolution for examining fluctuations in populations and seasonal effects.

Not all recommendations were able to be incorporated into the 2004 monitoring program as an October reporting deadline limits survey periods (M. Bamford pers. comm.).

5.5.2 Waterbirds

Waterbirds have been found to be useful indicators in three ways: breeding by several species corresponds with high spring peak water levels; wetlands that provide open shallows and mudflats that are favoured for foraging by shorebirds and some ducks, and these habitats are vulnerable to invasion by phreatophytic vegetation if peak water levels are not achieved in at least some years; and open, permanent or near-permanent water is important as a drought refuge for waterbirds (see Section 2.5.4 for further details). These three points suggest that waterbird monitoring should target representative wetlands for their role in supporting breeding, shorebirds and in acting as drought refugia, such as:

- Loch McNess
- Lake Yonderup
- Pipidinny Swamp
- Coogee Springs
- Lake Nowergup
- Lake Joondalup
- Lake Goollelal
- Lake Jandabup
- Lake Mariginiup
- Lexia 94
- EPP Wetland 173
- Melaleuca Park Wetlands
- Edgecombe Seepage
• Lake Yakine
• Thomsons Lake
• North Lake
• Bibra Lake
• Yangebup Lake
• Kogolup Lake
• Twin Bartram Swamp
• BEENYUP Rd Swamp
• Forrestdale Lake.

The current uncertainty as to whether or not waterbird monitoring on the Jandakot mound will be continued during 2004. Uncertainties of this nature should be resolved as soon as possible so that seasonal sampling periods are not restricted.

5.6 Surface water and groundwater monitoring

An investigation of the relationship between monitored wetland and groundwater levels for 18 wetland sites on the Gnangara Mound and 10 wetland sites on the Jandakot Mound, was undertaken to identify any wetlands where anomalous relationships occur between water levels in wetlands and in monitoring bores (Rockwater 2003). As a result of this investigation, it was recommended that alternative monitoring bores (existing or new) may be required at the following wetlands as poor correlations exist between groundwater and surface water levels and groundwater gradients into and/or out of the wetlands area:

• Lake Yonderup
• Lake Joondalup
• Lake Nowergup
• Lake Thomson
• Forrestdale Lake
• Bibra Lake.

Alternative monitoring bores (existing or new) may also be required at the following wetlands as poor correlations exist between groundwater and surface water levels and evidence of perched water tables (Rockwater 2003):

• Coogee Spring
• Melaleuca Park EPP 173
• Shirley Balla Swamp
• Lake Thomson
• North Lake.

At the following wetlands alternative monitoring bores (existing or new) may similarly be required, as only moderate correlations exist between groundwater and
surface water levels and groundwater levels are declining more rapidly than wetland levels (Rockwater 2003):

- Lake Nowergup
- Lake Jandabup.

In addition, surface water data is required at the following wetlands before the relationship between groundwater and the wetland environment can be determined (Rockwater 2003):

- Lexia 94
- Lexia 186
- Melaleuca Park Dampland 78
- Pipidinny Swamp
- Egerton Seepage
- Edgecombe Seepage
- Kogolup Lake South
- Bibra Lake.

In some instances the distances between groundwater monitoring bores and actual wetlands has led to the extrapolation of inaccurate water levels. Specific recommendations regarding the location of staff gauges/monitoring bores at given wetlands include:

- the relocation of the staff gauge at Pipidinny Swamp to the large pond on southern side of access track as this pond is sampled annually as part of macroinvertebrate sampling and appears less artificial (Loomes and Froend 2001b). Ongoing water level monitoring and actual depth measurements are required to determine seasonality of Pipidinny Swamp (Loomes and Froend 2001b).

In a review of groundwater monitoring on the SCP, Aquaterra (2004) found little supporting evidence to justify the current frequency of groundwater monitoring. Monitoring is carried out either monthly or bi-annually (during April/May and October) although the frequency can vary depending on bore location and the specific purpose of monitoring. However, despite the lack of rationale, current monitoring regimes do capture winter peak and summer low groundwater levels, the two periods at a minimum a monitoring regime should capture (Aquaterra 2004). Aquaterra (2004) make the following recommendations for groundwater monitoring frequency, noting the general rule should be to determine the period of monitoring necessary so that sampling frequency does not bias evaluations of the data:

- For new candidate sites or existing bores added to the network from the optimisation process it is recommended that monthly water-levels are collected for a period of three years to characterise the aquifer response at each site. If water-levels vary little in magnitude, monitoring may be decreased to semi-annually or bi-annually. If there is irregular fluctuations or uncertainty in water-level behaviour, which cannot be attributed to a known event or land use change, more frequent monitoring may be required.
• Following the three-year period of monthly monitoring, assessment of the required monitoring at those new sites should be conducted. A review of sites currently monitored annually should be conducted to determine the best bi-annual sampling regime to capture both maximum and minimum trends.

A comprehensive list of recommended monitoring sites for each aquifer on the SCP and location points of monitoring bores is provided by Aquaterra (2004).

As outlined in Section 2.6, the monitoring of groundwater levels provides the best ‘early warning’ capability of the potential impacts of changing groundwater levels on ecosystem health as such measurements are a direct representation of groundwater levels and understanding the relationship between groundwater parameters and ecosystem health is critical to predicting and/or modelling the impacts of changing groundwater regimes. This parameter is however, only useful if we know how the ecosystem attributes and values respond to changes in groundwater levels. The need for the development of ecosystem and species response curves against water availability, enabling the use of early warning of change in groundwater levels (and rainfall) to infer the risk of these changes to the ecosystem, represents an opportunity to strengthen the relationship between monitoring and research activities, further refining and extending the scientific knowledge of the ecosystem.
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