SOUTH WEST YARRAGADEE

- ASSESSMENT OF VEGETATION SUSCEPTIBILITY AND POSSIBLE RESPONSE TO DRAWDOWN

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Background

It is possible that some vegetation communities and flora species would be influenced by local groundwater regime changes under the Water Corporation's South-West Yarragadee Proposal. Investigations to date have highlighted a number of areas that have the potential to be impacted.

The target areas include the riparian vegetation and adjacent terrestrial vegetation of the Blackwood River (and floodplain) and several tributaries of the Blackwood, associated wetlands / damplands / sumplands / sedgelands, and the northern Scott Coastal Plain. This includes woodlands, fringing woodlands, shrublands, permanent wetlands and seasonally inundated areas.

This report addresses the following;

1. Determination of the level of dependence of phreatophytic wetland and terrestrial vegetation in target areas. This includes description of susceptibility / tolerance categories for the vegetation community types described in detailed transect work by Mattiske Consulting P/L (2004) and extrapolation to the broader vegetation complexes where possible.
2. Possible response of phreatophytic vegetation communities to groundwater level declines.
3. Possible response of phreatophytic vegetation to long-term changes in water regimes.

1. Level of groundwater dependence and susceptibility of phreatophytic vegetation

Water sources of terrestrial vegetation

Possible water sources of terrestrial vegetation are comprised only of groundwaters (soil water and groundwater), directly recharged by precipitation. The soil layer between the soil surface and water table is termed the unsaturated zone, as soil pore spaces are not saturated with water. The term ‘zone of saturation’ is used to designate the subsurface water below the water table in which all voids between soil particles are filled with water (Freeze and Cherry, 1979). Immediately overlying the water table is the capillary fringe, also known as the tension-saturated zone (Freeze and Cherry, 1979), as the micro-pores are saturated with water and are held above the water table by capillary forces. Deep-rooted species with a dimorphic root structure have a large root capture zone and are therefore capable of using (if available) unsaturated soil moisture (both shallow and at depth) and groundwater (at depth), either derived from the capillary fringe or directly from the water table.

Gravitational movement of water through soils leaves medium pores filled with water and with thin films around soil particles (Atwell *et al*., 1999). This state is known as field capacity and will be retained indefinitely if soil surface evaporation and evapotranspiration is prevented. In clay soils, where soil particles and pores are small, water is held by matric forces and does not drain freely (Atwell *et al*., 1999). Clay soils are therefore able to store large amounts of water, which is available to plants where root length and density are suitable. Sandy soils, in contrast have larger particles and pores, which drain freely and store less water (Atwell *et al*., 1999).

Assessment of bore logs from the South West Yarragadee study area indicates both sand and clay soils occur across the area, with sandy soils often underlain by clay and/or silt layers. It is possible that vegetation overlying shallow, accessible clay soils may be less susceptible to groundwater decline.

Approach

Susceptibility / tolerance categories were based on previous investigations into the dependence of phreatophytic terrestrial, riparian and fringing tree species on various groundwater regimes (Froend, Loomes and Zencich, 2002; Froend and Zencich, 2001; Froend and Loomes, 2004a; Froend *et al.*, 2004). Figure 1 shows the three vegetation categories that have demonstrated phreatophytic behaviour to date;

- 0-3 m
- 3-6 m
- 6-10 m.

The greater the depth to groundwater, the lower the requirement for groundwater and the more tolerant vegetation is to water table decline due to the corresponding increase in alternative water sources. These alternative sources are primarily the larger volume of unsaturated zone (with increasing depth) exploitable by the plant's root system.

Currently, quantitative information suggests reduced importance of groundwater to vegetation existing at depths to groundwater of >10 m. However, it is assumed that at depths of 10-20 m there is a probability of vegetation groundwater use, although it is thought to be negligible in terms of total plant water use, and that at depths of 20+ m this probability is substantially lower.

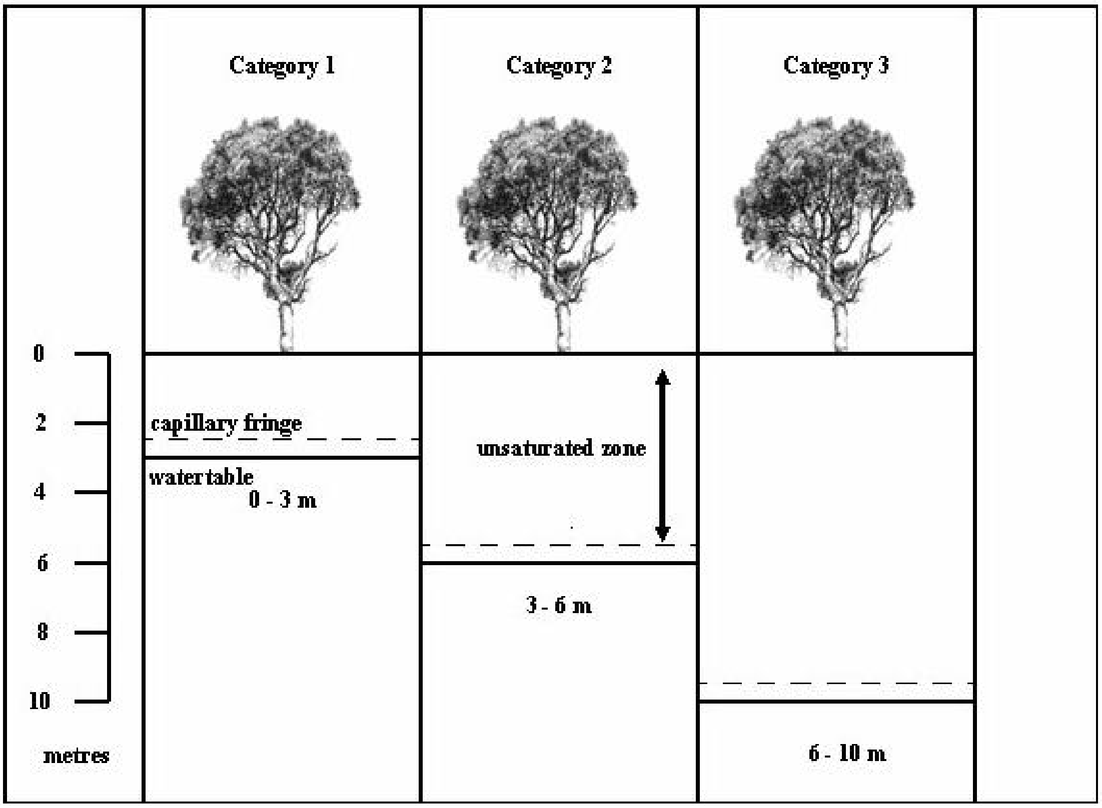

Figure 1: Categories of maximum depth to groundwater that have demonstrated phreatophytic behaviour in sandy soils. Clay soils may have more extensive capillary zone of up to 2 or 3 m.

Within the categories of 0-3 m, 3-6 m and 6-10 m (Figure 1), tree species are thought to be phreatophytic and to derive some water from groundwater throughout the year. Between these categories the degree to which groundwater is utilised is dependent on the proximity to groundwater, availability of moisture in shallower horizons in the soil profile, root system distribution, maximum root depth and groundwater quality. The highest proportion of groundwater (>50% of daily summer water use) is used by the 0-3 m and 3-6 m depth to groundwater vegetation category. Given the apparent high dependency of trees in these shallow areas on summer access to groundwater, it is suggested that they are particularly susceptible to groundwater drawdown. Vegetation in the 6-10 m category also uses groundwater however, it uses proportionally more water from the upper layers of the soil profile as it has a larger subsurface soil moisture store beyond the influence of direct evaporation.

Although the depth to groundwater categories were developed based on studies of *Banksia* sp., this approach has been successfully applied to a range of different vegetation types including wetland and riparian vegetation (Froend, Loomes and

Zencich, 2002; Froend and Loomes, 2004a; Froend *et al*., 2004) and is therefore applicable to this study. The categories were applied to the study areas to identify vegetation units (Table 1) that occur over shallow groundwater and are therefore the most susceptible to water level changes.

As the transect and vegetation unit scale mapping were undertaken at vastly different scales, transect and study site vegetation mapping were considered separately. At the transect scale, units identified across each transect were compared to depth to groundwater contours and then categorised to determine which were most susceptible (Tables 2). Where multiple depth to groundwater categories were represented within one vegetation unit the most susceptible (ie. the shallowest) was considered representative. This process was then repeated at the site scale, where the entire groundwater level range of each vegetation unit was considered (Table 3).

As discussed previously, it is possible that vegetation overlying shallow, accessible clay soils will be less susceptible to groundwater decline than vegetation overlying sandy soils due to greater water retention. However, although bore logs were available from across the study area, the majority of bores were located some distance (47 m – 630 m) away from the vegetation transects. As the gradient in soil types will vary even within a 100 m transect as it runs from riverbank to an upslope area, it is problematic to imply that the stratigraphy underlying the transects will bear some resemblance to that recorded at the nearest bore. However, where bores were located within 500 m of a transect (as indicated on maps: transect_veg&dtwt&bores) and stratigraphy was available, general comments were made on the possibility of reduced vegetation susceptibility to groundwater decline. It must be noted that the data and mapping provided allowed this assessment to be undertaken on less than 50% of transects.

Table 1: Description of vegetation unit codes used by Mattiske Consulting PL (2004).

Vegetation unit code	Vegetation unit description
A1	Closed heath of *Taxandria parviceps, T. linearifolia, Hypocalymma angustifolium, Beaufortia sparsa, Hypocalymma cordifolium* and *Acacia divergens* over range of sedges with pockets of *Melaleuca preissiana* and *Banksia littoralis.*
A2	Closed heath of *Melaleuca lateritia* over *Baumea vaginalis, Myriophyllum limnophilum* and *Triglochin huegelii*.
A3	Closed heath of *Melaleuca lateritia, Taxandria linearifolia, Hypocalymma angustifolium* and *Beaufortia sparsa* over range of sedges with pockets of *Eucalyptus rudis* and *Banksia littoralis.*
A4	Low sedgeland of *Schoenus subfascicularis* in open heath of *Acacia pulchella* var. *pulchella, Adenanthos meisneri, Sphaerolobium fornicatum* and *Daviesia decurrens.*
B1	Low open forest of *Eucalyptus marginata* subsp. *marginata, Corymbia calophylla, Xylomelum occidentale – Banksia attenuata – Banksia ilicifolia* over *Taxandria parviceps, Hypocalymma angustifolium* and *Acacia extensa* and a range of low shrubs and herbs.
C1	Open forest of *Eucalyptus marginata - Corymbia calophylla – Eucalyptus patens* over *Trymelium floribundum, Taxandria parviceps, Taxandria linearifolia, Hypocalymma cordifolium, Astartea scoparia* and *Gastrolobium bliobum* over *Baumea vaginalis* and *Lepidosperma gladiatum.*
C4	Open forest of *Corymbia calophylla – Eucalyptus patens – Banksia littorals* with occasional *Banksia seminude* over *Agonis flexuosa, Trymelium floribundum* and *Taxandria linearifolia* over *Bossiaea aquifolium* subsp. *laidlawiana, Lepidosperma gladiatum, Lepidosperma tetraquetrum* and *Baumea vaginalis.*
C5	Open forest of *Eucalyptus rudis, Agonis flexuosa, Melaleuca rhaphiophylla* over patches of *Melaleuca viminea, Astartea scoparia, Taxandria linearifolia* and *Lepidosperma gladiatum, Lepidosperma tetraquetrum* and *Baumea vaginalis.*
D1	Low open forest of *Banksia attenuata, E. marginata* subsp. *marginata* over *Taxandria parviceps, Mesomelaena tetragona, Hakea ruscifolia, Melaleuca thtmoides* and a range of low shrubs and herbs.
D3	Woodland of *Eucalyptus marginata* subsp. *marginata - Corymbia calophylla* over *Baeckea camphorosmae, Hypocalymma angustifolium* and *Meeboldinia species.*
Q1	Open forest of *Corymbia calophylla – Eucalyptus patens – Eucalyptus rudis - Eucalyptus marginata* subsp. *marginata* over occasional *Banksia littoralis* over *Pteridium esculentum, Gastrolobium bliobum , Acacia alata* var. *alata* and *Trymelium floribundum.*
S1	Open forest of *Eucalyptus marginata* subsp. *marginata - Corymbia calophylla* over occasional *Banksia grandis* over *Podocarpus drouynianus, Xanthorrhoea preissiana* and *Macrozamia riedlei*.
S2	Open forest of *Eucalyptus marginata* subsp. *marginata - Corymbia calophylla, Allocasuarina fraseriana, Xylomelum occidentale* over *Dryandra lindleyana var. lindleyana, Dasypogon hookeri, Hakea amplexicaulis, Adenanthos barbiger* and a range of low shrubs and herbs.
T1	Open forest of *Corymbia calophylla - Eucalyptus marginata* subsp. *marginata* over occasional *Banksia littoralis, Agonis flexuosa* over *Pteridium esculentum, Clematis pubescens* and *Leucopogon vertiverticillatus, Leucopogon australis, Bossiaea linophylla* and *Acacia brownlana* var. *browniana.*
W1	Open forest of *Eucalyptus marginata - Corymbia calophylla – Eucalyptus patens* over *Pteridium esculentum* and *Acacia alata* var. *alata.*

NB Vegetation unit descriptions for units S3, J1, A6 and A7 (Scott Coastal Plain) have not been provided.

Transect scale assessment

It is difficult to comment on transect-scale susceptibility as transect mapping does not indicate the dominance of individual species across the site. Comparison of depth to groundwater and species distribution also suggested that some species known to require relatively ‘wet’ conditions may be relying on the surface water component of the system rather than groundwater. Therefore vegetation unit mapping across each transect is compared to groundwater depth to determine which units are likely to be most susceptible. Descriptions of susceptibility based on species composition of vegetation units are included in the following section (study site scale assessment).

Table 2 shows that within the Layman Brook area vegetation units C5 and Q1 (see Table 1) in the 0-3 m groundwater depth category on transect 16 were most susceptible. Followed by units Q1, T1 and C5 at 3-6 m on transects 15 and 16. These units occurred within the Blackwood and Kingia vegetation complexes. In these vegetation complexes the units Q1 and T1 also occurred at greater than 6 m depth to groundwater. The remaining vegetation units (C1, S1 and W1) occurred within the Blackwood complex at depths greater than 10 m.

Although the closest bore (BP56A) was 122 m and 170 m away from transects 15 and 16 respectively, it is unlikely that the stratigraphy underlying the transects will bear any resemblance to that recorded at the bore. However, a potential water retention layer was noted between 4-5 m beneath the bore. The most susceptible vegetation occurs at 0-3 m on transect 16 and is considered beyond the influence of the potential retention layer. The 3-6 m category is present at both transects and the potential retention layer occurs within this category and therefore it is possible that this vegetation may be less susceptible to groundwater drawdown than other vegetation of the same depth to groundwater category. The 6-10 m category also occurs at both transects but is below the potential retention layer. If groundwater drawdown exceeds the lower limit for the 6-10 m category it is likely that more pressure will be placed on the retention layer above as species from both the 3-6 m and 6-10 m depth to groundwater categories access this source.

Across the Milyeannup Brook study site vegetation units C4, Q1 and T1 in the 0-3 m category on transects 5, 7 and 8 were the most susceptible, followed by C4, Q1, T1 and S1 in the 3-6 m category on transects 5, 7 and 8 (Table 2). Units S1 and T1 on transect 5, 6, 7 and 8 and Q1 on transects 5, 6 and 7, and C4 on transect 6 in the 6-10 m category were less susceptible, with S1 on transect 5 in the >10 m the least susceptible. All vegetation units on the Milyeannup Brook transect occurred within the Jalbaragup vegetation complex.

Although the closest bore (BP60A) was 185 m and 200 m away from transects 6 and 7 respectively it is unlikely that the stratigraphy underlying the transects will bear any resemblance to that recorded at the bore. However, a potential water retention layer was noted between 5-6 m beneath the bore. The water table across transect 6 (6-10 m) is below the potential water retention layer and is therefore considered beyond its influence. At transect 7 the most susceptible vegetation occurs at 0-3 m and is considered beyond the influence of the potential retention layer. The potential retention layer occurs within the 3-6 m category and therefore it is possible that this vegetation may be less susceptible to groundwater drawdown than other vegetation of the same depth to groundwater category. The 6-10 m category occurs below the potential retention layer however, if groundwater drawdown exceeds the lower limit for the 6-10 m category it is likely that more pressure will be placed on the retention layer above as species from both the 3-6 m and 6-10 m depth to groundwater categories access this source.

Transect 5 was 70 m from the closest bore (BP38A). A layer of silt/sand/clay was recorded near the ground surface at the bore (0-0.75 m). The most susceptible vegetation occurs at 0-3 m and it is possible that this vegetation may be less susceptible to groundwater drawdown than other vegetation of the same depth to groundwater category. The 3-6 m and 6-10m categories occur below the potential retention layer however, if groundwater drawdown exceeds either of these categories lower limits (eg. 6 m or 10 m) it is likely that more pressure will be placed in the retention layer as species from all depth to groundwater categories access this source.

The most susceptible vegetation units across the Poison Gully site were S2, A1 and B1 at transects 1, 9 and 14 and Q1 at transects 10 and 23 and C4 at transect 10 and C5 at transect 23 in the 0-3 m category. These units occurred within the Layman, Bidella and Jalbaragup vegetation complexes. Susceptible vegetation units in the 3-6 m category were S2 at transects 1, 2 and14, B1 and C1 at transect 2, T1 and Q1 at transects 23 and 10, S1 at transect 10 and A2 and D1 at transect 24. These units were within the Layman, Bidella, Blackwood and Jalbaragup complexes. Units occurring in the 6-10 m category were T1 on transects 23 and 10, S2 on transects 2 and 3, A1 and A4 on transect 3, B1 on transects 2 and 4, C1 on transect 4 and T1, D1 and A2 on transect 24. These units were within the Layman, Bidella and Blackwood complexes. The remaining units (S2 on transects 2, 3 and 4 and B1 on transect 4) were in the >10 m category within the Bidella complex.

Transect 1 was 190 m from the closest bore (BP51B). A layer of sand/clay was recorded between 3.5 and 5.0 m at the bore. The most susceptible vegetation occurs at 0-3 m, above this level and is therefore unlikely to be influenced by the potential retention layer. However, vegetation at 3-6 m may be less susceptible to drawdown than other vegetation of the same depth to groundwater category.

Transect 2 was 110 m from the closest bore (BP21C). A layer of sand/silt was noted between 1.5 and 6.4 m at the bore. As the depth to groundwater across the majority of the transect is below this level, it is possible that vegetation may be less susceptible to groundwater drawdown than other vegetation of the same depth to groundwater categories. However due to the retention layer only occupying the first 0.4 m of the 6-10 m category it is likely that if groundwater drawdown exceeds 10m that more pressure will be placed in the retention layer as species from the 3-6 m and 6-10m depth to groundwater categories access this source.

Transects 3 and 4 were 190 m and 82 m from the closest bores (BP59A and BP53A respectively). A layer of sand/clay was noted between 12.0 and 12.75 m at bore BP59A. As the depth to groundwater across transect 3 is generally above this level it is unlikely that the water retention layer will have an influence unless the water table drops below it. There was no retention layer noted at bore BP53A therefore vegetation retains the same level of susceptibility.

The closest bore (BP52A) was 47 m away from transect 9 and it is unlikely that the stratigraphy underlying the transect will bear any resemblance to that recorded at the bore. However, a potential water retention layer was noted between 3.0 and 3.75 m. Across transect 9 the most susceptible vegetation occurs in the 0-3 m category and is considered beyond the influence of the potential retention layer.

Table 2 shows that within the Rosa Brook area all vegetation units (C4, T1, S1 and Q1) on transect 32 and C5 on transect 30 and C1 on transect 31 in the 0-3 m groundwater depth category were most susceptible. These units occurred within the Darradup vegetation complex. Susceptible vegetation units in the 3-6 m depth to groundwater category were T1, Q1 and C5 on transect 30 and S1, W1 and C1 on transect 31. Units Q1 and S1 on transects 30 and 31 respectively are less susceptible being in the 6-10 m category.

Table 2 shows that within the Scott Coastal Plain area all vegetation units (S3, J1 and A7) in the vegetation complex Jangardup Scott (Dunes) on transect 27 and units J1, A7 and A6 on transect 29 (Coate vegetation complex) are most susceptible. Susceptible vegetation units in the 3-6 m category include all units (S3, J1 and A7) on transect 28 and S3 and J1 on transect 29. These units occurred within the Coate vegetation complex. Units in the 6-10 m category are S3, J1 and A6 on transect 25 (Scott Dunes vegetation complex). Least susceptible are the units in the >10 m category which are all units (S3, J1 and A7) in the Nillup Scott (dunes) vegetation complex and units S3, J1 and A6 from the Scott (dunes) vegetation complex.

Summary of Transect Scale Assessment

Application of the depth to groundwater categories to the transect scale assessment identified vegetation units that occurred over shallow groundwater and are therefore susceptible to water level changes. Areas of vegetation from units A1, A6, A7 B1, C1, C4, C5, J1, Q1, S1, S2, S3 and T1 at groundwater depths of 0-3 m are most susceptible, followed by vegetation of the same units at 3-6m and then 6-10m. Although vegetation at 10-20 m may show some groundwater dependence it is thought to be negligible in terms of total plant water use, and at depths of 20m+ this probability is substantially lower.

At the Layman Brook site the most susceptible vegetation (0-3 m depth to groundwater) occurs in the Q1 and C5 units within the Kingia complex located immediately north of the Layman Brook Blackwood River junction. At the Milyeannup Brook site the most susceptible vegetation (0-3 m) occurs in the Q1, C4 and T1 units within the Jalbaragup complex located south of the junction of Milyeannup Brook and the Blackwood River and in and adjacent to the channel of the northern reaches of Milyeannup Brook.

At the Poison Gully site the most susceptible vegetation (0-3 m) includes units C4, C5, B1, A1, S2 and Q1 in the Layman, Bidella and Jalbaragup complexes within and adjacent to the Blackwood River. At the Rosa Brook site the most susceptible vegetation (0-3 m) includes units C5, C1, S1, Q1, C4 and T1 in the Darradup vegetation complex. Finally at the Scott Coastal Plain site the most susceptible vegetation (0-3 m) includes units 3, J1, A7 and A6 in the Coate, Jangardup and Scott (dunes) vegetation complexes.

Although bore logs were available from across the study area, the majority of bores were located some distance (47 m – 630 m) away from the vegetation transects. As the gradient in soil types will vary even within a 100 m transect as it runs from riverbank to an upslope area, it is problematic to imply that the stratigraphy underlying the transects will bear some resemblance to that recorded at the nearest bore. However, where a potential water retention layer was noted within a depth to groundwater category the vegetation in that category was considered to be less susceptible to groundwater decline than other vegetation of the same depth to groundwater category. If the depth to groundwater category was above the potential water retention layer then that vegetation was considered to be beyond its influence. Finally if the depth to groundwater category was below the potential retention layer then the vegetation was also considered to be beyond its influence however, if the groundwater were to declined below the lower limit of that category then it is likely to place extra pressure on the retention layer as multiple depth to groundwater categories are likely to access the source.

Table 2: Distribution, groundwater depth ranges and categories of vegetation complexes and units across transects at the five target sites.

Site/ Transect no.	Transect length (m)	Vegetation complex	Distance along transect (m)	Vegetation unit	Depth to ground/ water category	Closest bore / distance from start of transect (m)	Depth of potential retention layer (m) at bore
Layman Brook							
11	100	Blackwood	0-5	S1	>10m	Unknown	Unknown
			5-30	T1	>10m		
			30-40	C1	>10m		
			40-65	T1	>10m		
			65-100	S1	>10m		
12	100	Blackwood	0-10m	S1	>10m	Unknown	Unknown
			10-45m	W1	>10m		
			45-65	C1	>10m		
			65-75	W1	>10m		
			75-100	S1	>10m		
13	100	Blackwood	0-25	W1	>10m	Unknown	Unknown
			25-45	C1	>10m		
			45-80	W1	>10m		
			80-100	S1	>10m		
15	120	Blackwood	0-5	S1	>10m	BP56A - 122	Sand/silt: 4 - 5
			5-15m	T1	6-10m		
			15-20	T1	3-6m		
			20-30	Q1	3-6m		
			30-67.3	C5	3-6m		
			67.3-70	C5	>10m		
			70-110	Q1	>10m		
			110-120	T1	>10m		
16	100	Kingia	0-15	T1	3-6m	BP56A - 170	Sand/silt: 4 - 5
			15-20	T1	6-10m		
			20-30	T1	3-6m		
			30-45	Q1	3-6m		
			45-50	Q1	6-10m		
			50-60	Q1	3-6m		

Site/ Transect no.	Transect length (m)	Vegetation complex	Distance along transect (m)	Vegetation unit	Depth to ground/ water category	Closest bore / distance from start of transect (m)	Depth of potential retention layer (m) at bore
			60-70	Q1	0-3m		
			70-100	C5	0-3m		
Milyeannup Brook							
5	180	Jalbaragup	0-30	S1	>10m	BP38A - 70	Sand/silt/clay: 0 - 0.75
			30-35	S1	6-10m		
			35-45	T1	6-10m		
			45-55	Q1	6-10m		
			55-65	Q1	3-6m		
			65-75	C4	0-3m		
			75-100	Q1	3-6m		
			100-155	Q1	0-3m		
			155-170	T1	0-3m		
			170-175	T1	3-6m		
6	100	Jalbaragup	0-5	S1	6-10m	BP60A - 185	Silt/sand: 5 - 6
			5-25m	T1	6-10m		
			25-45	Q1	6-10m		
			45-65	C4	6-10m		
			65-85	Q1	6-10m		
			85-100	T1	6-10m		
7	100	Jalbaragup	0-5	S1	6-10m	BP60A - 200	Silt/sand: 5 - 6
			5-20m	T1	6-10m		
			20-45	Q1	6-10m		
			45-80	Q1	3-6m		
			80-90	C4	0-3m		
			90-100	C4	3-6m		
8	160	Jalbaragup	0-15	S1	6-10m	Unknown	Unknown
			15-20	T1	6-10m		
			20-40	T1	3-6m		
			40-60	T1	0-3m		
			60-90	Q1	0-3m		

Site/ Transect no.	Transect length (m)	Vegetation complex	Distance along transect (m)	Vegetation unit	Depth to ground/ water category	Closest bore / distance from start of transect (m)	Depth of potential retention layer (m) at bore
			90-95	Q1	3-6m		
			95-100	Q1	0-3m		
			100-110	C4	0-3m		
			110-125	Q1	3-6m		
			125-150	T1	3-6m		
			150-160	S1	3-6m		
Poison Gully							
1	200	Jalbaragup	0-40	S2	3-6m	BP51B - 190	Sand and clay: 3.5 - 5
			40-50	S2	0-3m		
			50-115	A1	0-3m		
			115-175	B1	0-3m		
			175-195	S2	0-3m		
2	160	Bidella	0-15	S2	6-10m	BP21C - 110	Sand/silt: 1.5 - 6.4
			15-25	S2	3-6m		
			25-45	B1	3-6m		
			45-75	C1	3-6m		
			75-80	B1	3-6m		
			80-115	B1	6-10m		
			115-135	S2	6-10m		
			135-160	S2	>10m		
3	240	Bidella	0-30	S2	>10m	BP59A - 190	Sand/clay: 12 - 12.75
			30-45	S2	6-10m		
			45-95	A1	6-10m		
			95-205	A4	6-10m		
			205-240	S2	6-10m		
4	140	Bidella	0-25	S2	>10m	BP53A - 82	Sand: 0 - 14.25
			25-35	B1	>10m		
			35-45	B1	6-10m		
			45-60	C1	6-10m		
			60-70	B1	6-10m		

Site/ Transect no.	Transect length (m)	Vegetation complex	Distance along transect (m)	Vegetation unit	Depth to ground/ water category	Closest bore / distance from start of transect (m)	Depth of potential retention layer (m) at bore
			70-90	B1	>10m		
			90-140	S2	>10m		
9	140	Layman	0-10	B1	0-3m	BP52A - 47	Sand/clay: 3 - 3.75
			10-40m	A1	0-3m		
			40-130	B1	0-3m		
			130-140	S2	0-3m		
10	80	Layman	0-5	S1	3-6m	Unknown	Unknown
			5-10m	T1	3-6m		
			10-20m	Q1	0-3m		
			20-40	C4	0-3m		
			40-50	Q1	0-3m		
			50-65	Q1	3-6m		
			65-80	T1	6-10m		
14	100	Bidella	0-20	S2	0-3m	Unknown	Unknown
			20-35	B1	0-3m		
			35-70	A1	0-3m		
			70-80	B1	0-3m		
			80-85	S2	0-3m		
			85-100	S2	3-6m		
23	60	Layman	0-20	T1	6-10m	Unknown	Unknown
			20-25	T1	3-6m		
			25-30	Q1	3-6m		
			30-40	Q1	0-3m		
			40-60	C5	0-3m		
24	120	Blackwood	0-10	T1	6-10m	Unknown	Unknown
			10-25m	D1	6-10m		
			25-40	A2	6-10m		
			40-100	A2	3-6m		

Site/ Transect no.	Transect length (m)	Vegetation complex	Distance along transect (m)	Vegetation unit	Depth to ground/ water category	Closest bore / distance from start of transect (m)	Depth of potential retention layer (m) at bore
			100-120	D1	3-6m		
Rosa Brook							
30	100	Darradup	0-20	T1	3-6m	Unknown	Unknown
			20-40	Q1	3-6m		
			40-50	C5	0-3m		
			50-55	C5	3-6m		
			55-75	Q1	6-10m		
			75-80	Q1	3-6m		
			80-100	T1	3-6m		
31	160	Darradup	0-20	S1	6-10m	Unknown	Unknown
			20-50	S1	3-6m		
			50-110	W1	3-6m		
			110-115	C1	0-3m		
			115-125	C1	3-6m		
			125-160	W1	3-6m		
32	100	Darradup	0-25	S1	0-3m	Unknown	Unknown
			25-35	Q1	0-3m		
			35-65	C4	0-3m		
			65-90	Q1	0-3m		
			90-100	T1	0-3m		
Scott Coastal Plain							
25	225	Scott (dunes)	0-60	S3	6-10m	Unknown	Unknown
			60-105	S3	>10m		
			105-155	J1	>10m		
			155-170	J1	6-10m		
			170-175	A6	6-10m		
			175-220	A6	>10m		
26	160	Nillup, Scott (dunes)	0-45	S3	>10m	Unknown	Unknown
			45-75	J1	>10m		
			75-160	A7	>10m		

Site/ Transect no.	Transect length (m)	Vegetation complex	Distance along transect (m)	Vegetation unit	Depth to ground/ water category	Closest bore / distance from start of transect (m)	Depth of potential retention layer (m) at bore
27	160	Jangardup, Scott (dunes)	0-45	S3	0-3m	Unknown	Unknown
			45-110	J1	0-3m		
			110-160	A7	0-3m		
28	140	Coate	0-40	S3	3-6m	BP33 - 630	Unknown
			40-95	J1	3-6m		
			95-140	A7	3-6m		
29	180	Coate	0-15	S3	3-6m	Unknown	Unknown
			15-30	J1	3-6m		
			30-55	J1	0-3m		
			55-135	A7	0-3m		
			135-180	A6	0-3m		

Study site scale assessment

Table 3 illustrates the relative susceptibility of vegetation units and complexes across all study sites. As described previously vegetation in areas of 0-3 m depth to groundwater was regarded as the most susceptible. Consideration of vegetation unit mapping at the study site scale (Layman Brook, Milyeannup Brook, Poison Gully) showed that vegetation of Q1, C1, C4, C5, S2, A1, A2, A3, T1 and B1 occurred at these shallow depths. Unit T1 also occurred in areas of 3-6 m along with vegetation of the S1, D3, units. Only two units were identified in areas of 6-10 m to groundwater, C4 and C1, with both also having occurred in the 0-3 m category.

Vegetation unit descriptions (Table 1) identify the dominant species within each unit and provide some further indication of susceptibility. However, due to the mapping scale some of the units occur across a range of depth categories making it difficult to comment accurately on susceptibility at the unit and species scale. With this in mind the following comments can be made on the relative susceptibility of individual units based on depth to groundwater and species composition. Units are discussed in order of possible susceptibility based on overall water depth ranges.

Unit C5 was classified as occurring in the 0-3 m groundwater depth category however, overall it occurred at some of the shallowest depths across all study areas (0-12 m). C5 is therefore likely to represent the vegetation most susceptible to groundwater decline. Dominant tree species include *Eucalyptus rudis* and *Melaleuca rhaphiophylla* both known to be susceptible to groundwater decline (Froend *et al.*, 2002). The large shrub *Taxandria linearifolia* and the sedge species *Baumea vaginalis* also respond negatively to groundwater decline. Vegetation of this unit occurred at Layman Brook, Milyeannup Brook and Poison Gully.

Vegetation of the A1 unit was classified as occurring in the 0-3 m category however, its overall range was 0-15 m to groundwater. The majority of species described as dominant in this unit are known to be susceptible to groundwater decline, especially *Banksia littoralis* and ‘sedge’ species. The tree species *Melaleuca preissiana* and the shrubs *Hypocalymma angustifolium* and *Beaufortia sparsa* are also generally groundwater dependent however, are more likely to be found at greater depths to groundwater within this unit. Vegetation of this unit occurred at Poison Gully.

Unit A2, classified in the 0-3 m category, occurred between 2.0 and 7.0 m to groundwater. Although the species listed for this unit may be impacted by groundwater decline, it is likely that they are more dependent on the surface water component of the system, as both *Triglochin huegelii* and *Myriophyllum limnophilum* are aquatic species. The shrub *Melaleuca lateritia* and sedge species *Baumea vaginalis* are generally associated with swampy areas. Vegetation of this unit occurred at Poison Gully.

Vegetation of the A3 unit was classified as occurring in the 0-3 m category however, its overall range was 2-12 m to groundwater. The dominant tree species, *B. littoralis* and *E. rudis* are known to be susceptible to groundwater decline as are the shrub species associated with this unit (Froend *et al*. 2002). Vegetation of A3 also only occurred at Poison Gully.

Although unit B1 was also classified as occurring in the 0-3 m category, its overall water depth range was 0-24 m. A small number of dominant species in this unit (*H. angustifolium* and *B. ilicifolia*) may respond to groundwater decline however, the majority of the vegetation has not been shown to be groundwater dependent. Vegetation of this unit only occurred at Poison Gully.

Vegetation of the T1 unit was classified as occurring in the 0-3 m and 3-6 m categories however, its overall range was 2-28 m to groundwater. The only phreatophytic species listed as dominant in this unit is *B. littoralis*. Other tree and shrub species are not likely to be susceptible to groundwater decline. Vegetation of T1 occurred at Layman Brook, Milyeannup Brook and Poison Gully.

Unit C4, classified in the 0-3 and 6-10 m categories, occurred between 1.0 and 32.0 m to groundwater. Although some of the species listed as dominant are susceptible to groundwater decline; *B. littoralis* and the sedge species *Lepidosperma tetraquetrum* and *Baumea vaginalis*, the majority of species are currently not considered to be phreatophytic. It is possible that ‘wet’ elements of the vegetation dominate areas of shallow groundwater while more xerophytic species occur at greater depths. Vegetation of this unit occurred at Layman Brook, Milyeannup Brook and Poison Gully.

Vegetation of the C1 unit was classified as occurring in the 0-3 and 6-10 m categories however, its overall range was 1-33 m to groundwater. None of the dominant tree species listed for this unit are currently considered to be phreatophytic however, the shrub *Astartea scoparia* and sedge *B. vaginalis* are susceptible to groundwater decline. Vegetation of C1 occurred at Layman Brook, Milyeannup Brook and Poison Gully.

Although unit Q1 was also classified as occurring in the 0-3 m category, its overall water depth range was 0-40 m. This range in water depth distribution may be explained by the composition of the overstorey which comprises both 'wetland' (*E. rudis* and *B. littoralis*) species and those currently considered non-phreatophytic (*Corymbia calophylla* and *E. marginata* subsp.). It is possible that 'wet' elements of the vegetation dominate areas of shallow groundwater while more xerophytic species occur at greater depths. Vegetation of this unit occurred at Layman Brook, Milyeannup Brook and Poison Gully.

Unit S2, classified in the 0-3 m category, occurred between 1.0 and 37.0 m to groundwater. There were no phreatophytic species listed as dominant within this unit. Vegetation of S2 occurred at Layman Brook and Poison Gully.

Dominant vegetation of the remaining units, W1, S1, D3, D1 and A4 is generally unlikely to be susceptible to groundwater decline with the exception of *H. angustifolium* of unit D3 and *Schoenus subfascicularis* of A4.

Although there is vegetation unit mapping for the Rosa Brook study area, to date no groundwater contouring has been provided. There is currently no vegetation or groundwater contour mapping for the Scott Coastal Plain study area.

Summary of Study Scale Assessment

Application of the depth to groundwater categories to the study areas identified vegetation units that occur over shallow groundwater and are therefore susceptible to water level changes. Areas of vegetation from units A1, A2, A3, B1, C1, C4, C5, Q1, S2 and T1 at groundwater depths of 0-3 m are most susceptible, followed by vegetation of the same units at 3-6 m and then 6-10 m. Although vegetation at 10-20 m may show some groundwater dependence it is thought to be negligible in terms of total plant water use, and at depths of 20+ m this probability is substantially lower.

At the Layman Brook site the most susceptible vegetation (0-3 m depth to groundwater) occurs in the Q1 and C5 units. At the Milyeannup Brook site the most susceptible vegetation (0-3 m) occurs in the Q1, C4 and C5 units. At the Poison Gully site the most susceptible vegetation (0-3 m) includes units C4, C5, Q1, A1, A2, S2, C1, B1, A3 and T1.

Table 3: Groundwater depth ranges and categories of vegetation units across target sites.

Site	Vegetation unit	Depth to groundwater range (m)	Depth to groundwater category
Layman Brook			
	W1	21.0 -70.0	>10 m
	C1	10.0 -72.0	>10 m
	S1	25.0 - 68.0	>10 m
	T1	13.0 - 42.0	>10 m
	C4	7.0 - 11.0	6-10 m
	C5	1.0 - 8.0	0-3 m
	Q1	1.0 - 40.0	0-3m
	D3	59.0 - 66.0	>10 m
	S2	48.0 - 68.0	>10 m
	D1	48.0 - 51.0	>10 m
Milyeannup Brook			
	S1	11.0 - 39.0	>10 m
	T1	3.0 - 40.0	3-6 m
	Q1	1.0 - 32.0	0-3 m
	C5	0 - 11.0	0-3 m
	C1	6.0 - 38.0	6-10 m
	C4	1.0 - 32.0	0-3 m
	W1	13.0 - ?	>10 m
Poison Gully			
	T1	2.0 - 28.0	0-3 m
	Q1	0 - 25.0	0-3 m
	C4	0 - 20.0	0-3 m
	C5	0 - 12.0	0-3 m
	S1	4.0 - 38.0	3-6 m
	B1	0 - 24.0	0-3 m
	D3	3.0 - 15.0	3-6 m
	A1	0 - 15.0	0-3 m
	A2	2.0 - 7.0	0-3 m
	S2	2.0 - 37.0	0-3 m
	A3	2.0 - 12.0	0-3 m
	C1	1.0 - 33.0	0-3 m
	A4	12.0 - 14.0	>10 m

Conclusions

The results of this study indicate that the most susceptible vegetation units (with no consideration given to soil stratigraphy) across the SW Yarragadee study area are A1, A2, A3, A6, A7, B1, C1, C4, C5, J1, Q1, S1, S2, S3 and T1 in the 0-3 m depth to groundwater category. The majority of these units support vegetation components known to be groundwater dependent, including the 'wetland' tree species *Eucalyptus rudis, Melaleuca rhaphiophylla, M. preissiana* and *Banksia littoralis* along with terrestrial, phreatophytic species *B. attenuata* and *B. ilicifolia*. The most susceptible vegetation complexes appear to be Kingia, Jalbaragup, Layman and Bidella.

2. Possible response of phreatophytic vegetation to groundwater level decline.

As vegetation from each depth to groundwater category exhibits a different level of groundwater dependency, they will respond differently to the same changes in water regime. The following figures (2a-c) represent the current understanding of the potential response of phreatophytic vegetation to drawdown (Froend and Loomes, 2004b). To determine the level of potential impact (low, moderate, high or severe) the predicted rate of drawdown (m/yr) is read from the y axis and the magnitude from the x axis.

Comparison of the level of possible response (as identified in the figures below) to the corresponding column in Table 4, provides a description of the type of response of key elements of phreatophytic vegetation ecosystems to groundwater drawdown.

It must be noted that the possible response levels are preliminary and based on *Banksia* species common to the Swan Coastal Plain. However, it is likely that other plant species occupying similar niches (groundwater depth category) will exhibit a similar level of response. The response levels are approximate as further validation is required. It is not possible to be more specific about actual characteristics of phreatophytic vegetation response for the following reasons;

- Historic changes in groundwater tables and previous impacts on vegetation.
- Plant response will depend on the magnitude of response beyond the identified threshold of a category.
- The specific site conditions.
- The habitat type and species in question.
- Time period over which thresholds are exceeded.
- Secondary factors such as disturbance.

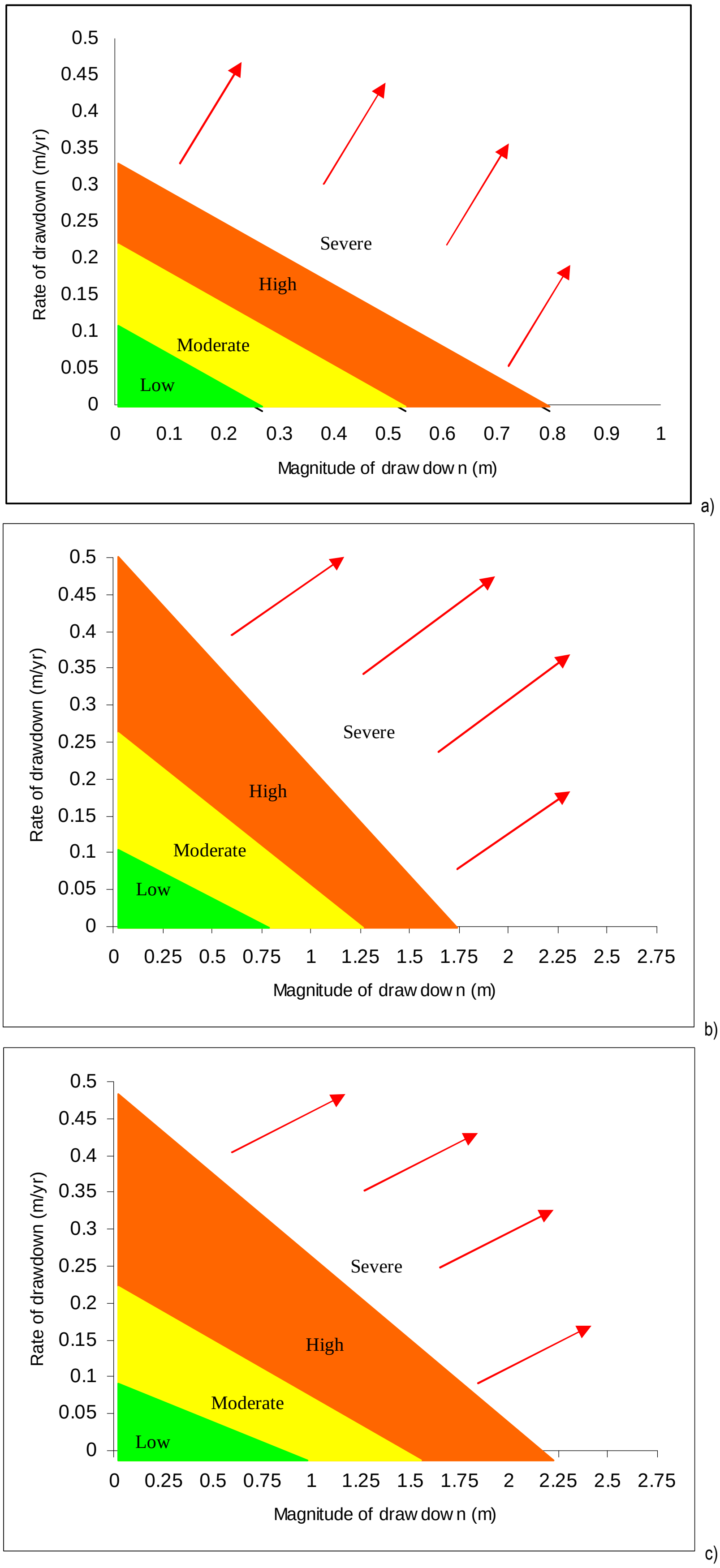

Figure 2: Possible level of response for phreatophytic vegetation in the different depth to groundwater categories based on rate and magnitude of groundwater level change a) 0-3 m, b) 3-6 m, c) 6-10 m.

Table 4: Possible response of key elements of phreatophytic vegetation communities to drawdown.

Key elements	Level and type of possible response to drawdown Low (no measurable change)	Moderate (small change)	High (moderate change)	Severe (large change)
Ecosystem processes				
- Primary production	Rates of primary production are maintained within the limits of natural variation.	Some evidence of reduction in rates of primary production in response to drying.	Measurable reductions in rates of primary production in response to drying.	Severe reductions in rates of primary production in response to drying.
- Nutrient recycling	Rates of nutrient recycling are maintained within the limits of natural variation.	Some evidence of reduction in rates of nutrient recycling in response to drying.	Measurable reductions in rates of nutrient recycling in response to drying.	Severe reductions in rates of nutrient recycling in response to drying.
- Foodchains	No measurable change in foodchains.	Some evidence of disruption to foodchains.	Measurable disruptions to foodchains.	Severe disruptions to foodchains.
- Sediment /soil stabilization	No measurable change in soil stabilisation.	No detectable change in soil stabilisation.	Some evidence of soil destabilisation/erosion.	Measurable destabilisation/erosion of soil.
Biodiversity				
- Species composition	No measurable change in species composition.	Some evidence of encroachment of more drought tolerant species.	Measurable signs of encroachment of more drought tolerant species.	Increased loss of less drought tolerant species from ecosystem, with establishment of exotic species and gradual dominance by more drought tolerant species.
- Species distribution	No measurable change in distribution of phreatophytic species (not measurable in past 20 years).	Some evidence of changing distribution and encroachment of more drought tolerant species into areas previously dominated by less drought tolerant species.	Measurable change in demographics of some species with encroachment of more drought tolerant species into areas previously dominated by less drought tolerant species.	Overstorey and understorey decline and/or loss of species from ecosystem. Greater than 50% reduction in abundance of dominant populations and/or disturbance allowing establishment of exotic species.
- Species mortality	No measurable mortality.	Some mortality of individuals.	Greater than 15% reduction in abundance of dominant species.	Greater than 50% reduction in abundance of dominant species.
- Species richness	No measurable changes in species richness.	Some evidence of decline in richness of less drought tolerant species.	Measurable decline in richness of less drought tolerant species and/or increase xeric species richness.	Significant change in richness of less drought tolerant species and replacement by more xeric species.
- Community structure	No measurable change in community structure.	Some evidence of change in community structure.	Notable change in community structure.	Significant change in community structure.
Abundances and biomass of biota				
- Vegetation density, cover and frequency	No measurable change in density, cover and abundance.	Some evidence of reduced growth in overstorey and/or understorey species.	Measurable crown dieback in overstorey species and/or reduction in cover of understorey.	Substantial crown dieback in overstorey species and loss of density and cover in understorey.
- Vegetation height and diameter	No measurable change in vegetation height and diameter.	Some evidence of change in height due to loss of vigour and/or thinning of canopy.	Measurable reductions in height due to loss of canopy and/or reduced diameter of adult stems.	Significant reductions in height due to loss of canopy and reduced diameter of adult stems.
- Vertebrate abundance	No measurable change in vertebrate abundance.	Some evidence of reduced vertebrate abundance.	Measurable changes in vertebrate abundance due to reduction in food and/or habitat availability as result of drying.	Greater than 50% reduction in vertebrate abundance due to reduction in food and/or habitat availability as result of drying.
- Macroinvertebrate abundance	No measurable change in macroinvertebrate abundance.	Some evidence of reduced macroinvertebrate abundance.	Measurable changes in vertebrate abundance due to reduction in food and/or habitat availability as result of drying.	Greater than 50% reduction in vertebrate abundance due to reduction in food and/or habitat availability as result of drying.

3. Possible response of phreatophytic vegetation to long-term changes in water regimes.

To predict the possible response of phreatophytic vegetation to long-term groundwater regime changes it is essential to consider the cumulative impacts of historic change and possible future changes in water levels as well as the current depth to groundwater and ecological condition of the vegetation. However, as historic water regime changes and current vegetation condition are not known, it is only possibly to make general comments on types of long-term responses that may occur. Based on phreatophytic vegetation studies on the Gnangara Mound over the last 10 years the following may be expected in the current study area in response to progressive long-term drying (Froend *et al.*, 2002).

Change in distribution

- Attributes

A gradual reduction in the available water to plants usually sees a change in distribution of plant species along the water-availability gradient. This is associated with changes in plant distribution in upland areas typical of shallow depths to groundwater as well as areas of permanent water that may occur. The character of vegetation distribution change is dependent on the following:

1. Resident plant species and their water requirements. Larger, perennial woody species are more tolerant to changes in water levels than annual or short-lived emergent/submerged plants. Phreatophytic vegetation will only continue to be represented in a community if their water requirements are met. Therefore, in cases of extreme change in water availability, local extinction may occur.
2. Sources of propagules for colonisation. Resident populations of phreatophytic species must reproduce for any change in distribution to occur. Populations that are not reproducing (tree species seed production being the best example) due to environmental conditions may not be capable of responding, leading to no change in distribution, significant lag-effect, or local extinction (despite habitat being available). Site conditions (habitat availability) will also determine the success of recruitment. Water regime changes may occur at a magnitude and rate that

effectively prohibits successful recruitment, leaving senescent populations of the most tolerant species only.

3. The magnitude of water level change. Significant changes in water level, irrespective of the rate of change, can eventually result in the loss of vegetation. The moister the water requirement, the more susceptible to altered water regimes.
4. The geomorphology of the area. The pattern of vegetation distribution change will be variable in areas with very shallow gradients in water availability such as broad, flat, low-lying areas. Change may be seen as widespread rather than limited to peripheral areas within the littoral fringe.

Change in distribution, such as vegetation encroachment towards lower elevations, has been observed to occur at variable rates. The rate of change in plant distribution is dependent on the following:

1. The mode of reproduction. Annual plants producing large quantities of seed lead to rapid changes in productivity and distribution. If suitable habitat is available, these plants are capable of rapid colonisation and effective competition, extending their distributions. Larger, woody plants that have slower (and lower) rates of seed production and high seedling mortality, are not capable of colonising available habitat as quickly.
2. Availability of new (suitable) habitat and interspecific interactions that arise through colonisation. If the distribution of vegetation is to change, new habitat must be available. Site conditions will determine the suitability of available habitat and if there is existing vegetation, establishing seedlings will need to compete for resources.
3. Rate of water decline (whether gradual over several years or rapid over 1 year). Slow, gradual rates of water level decline will result in slow changes in distribution (all other factors being constant). Rapid rates of decline however, are likely to result in obvious collapse of populations of susceptible species followed by recolonisation elsewhere (if conditions permit).
4. Permanency of reduced water levels (e.g short-term reduction and return before any significant change in vegetation). Decreases in water regime may be reversed after a short period (1-3 years), alleviating water stress on existing populations or allowing recolonisation of a species. Significant changes in distribution that have

occurred over several years can be reversed (although the character of the vegetation will not be identical) over an equivalent period of time.

Change in Composition

- Attributes

Changes in vegetation composition is perhaps more controversial with respect to loss of native species and gain of exotic species. The factors that influence the character and rate of composition changes are the same as for distribution. Some exceptions and additions are as follows:

1. Progressive drying results in alteration of habitat type that often leads to colonisation of more xerophytic species (more tolerant of drier conditions). The process of terrestrialisation is the gradual process of dryland plant species colonisation, encroachment and dominance of a site. This is usually a response to a gradual drying of an area to the point where water requirements of phreatophytic species can no longer be met. The consequent death of phreatophytic species and decline of their populations is followed by gradual colonisation and replacement by xerophytic dryland species with lower water requirements. The process is not irreversible and is commonly interrupted by changes in rainfall patterns and hydrological support mechanisms. Therefore, changes in rainfall pattern from the current ‘dry’ regime are likely to decrease or reverse the trend in flora composition dynamics.
2. The potential for colonisation by exotic plant species is increased if the impact of drawdown has resulted in canopy decline and suitable habitat for weeds becoming available. The potential for weed invasion depends on the proximity of propagule sources (e.g. from nearby agricultural land uses) and site conditions. Rapid and extensive weed growth has significant ramifications for native species recruitment success, preventing seedling establishment and increasing the risk of disturbance by fire.

Change in vigour

Measurable changes in the vigour of phreatophytic vegetation, associated with reduced water availability, are the precursor to changes in distribution and composition. As water requirements are not being met, the vigour of individuals within a population will decline (water stress, branch die-back, reduced growth, leaf shed, chlorosis), leading to loss of individuals at drier areas of the water availability gradient (altered distribution), or total loss of the local population (altered community composition). Due to gradients in water availability, there is the potential for extreme variability in vegetation vigour. Vegetation at the driest extreme of its distribution will always reflect the poorest (relative) vigour. As water levels gradually decline, a greater proportion of the vegetation will have poor vigour and die, with progressively less habitat for colonisation.

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