WATER SENSITIVE URBAN DESIGN

VEGETATION SELECTION GUIDE

FINAL

Prepared for the Northern Territory Department of Planning and Infrastructure
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1 INTRODUCTION

As part of preparing a WSUD Strategy for Darwin Harbour, a vegetation selection guide has been prepared to assist WSUD practitioners in the selection of appropriate vegetation species for WSUD treatment elements such as wetlands, bioretention systems and swales.

Most of the plants selected are Australian natives that occur naturally in the Top End. The majority of the plant species listed are known to occur naturally in the Top End and are adapted to conditions in the wet/dry tropics. Incorporating native plants into urban areas will add biodiversity and ecological habitat value to urban areas in the Darwin region. Vegetation planted as part of WSUD treatment systems performs many important functions in urban areas, such as visual amenity, soil stabilisation, microclimate control, fauna habitat, as well as its primary role as water pollution filtration and uptake of nutrients. It is recommended to seek advice from land managers, ecologists and landscape architects to determine that the plants used in each specific situation meet the needs of all the other site users.

1.1 Purpose of this Document

This document has been developed as part of Task 16b (Stage 6) of the Workplan. It is intended as a guide for developers, consultants, local councils, the Development Consent Authority (DCA) and the Department of Planning and Infrastructure (DPI) to design Water Sensitive Urban Design treatment systems. This document accompanies the "Standard Drawings", "Technical Design Guide" as well as various WSUD planning guidelines to form a set of guidelines and manuals on preparing and implementing a WSUD Strategy for a development application and for construction. The framework of guideline documents the relationship of this guideline to other guidelines is shown in Figure 1.

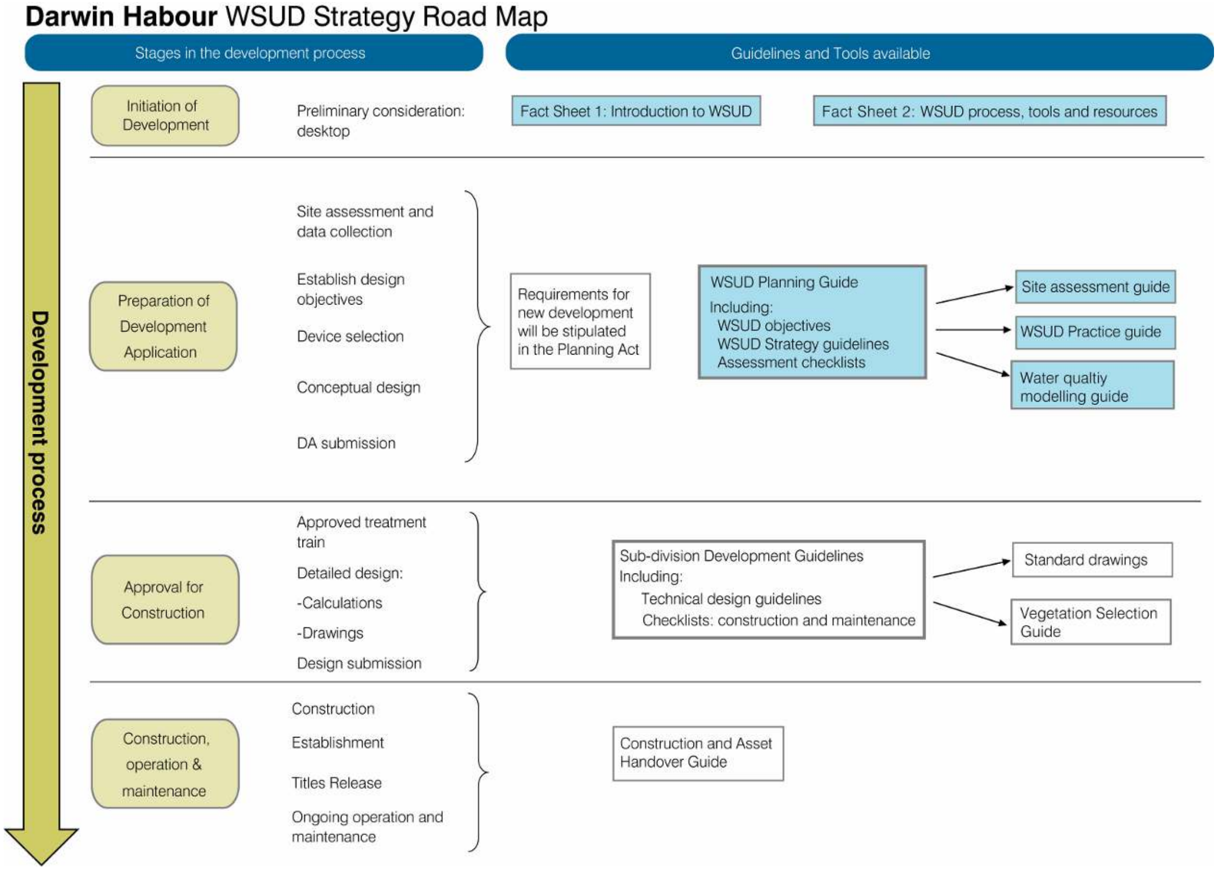


Figure 1: Relationship of the "vegetation Selection Guide" to other guidelines and tools

1.2 Outline of this Document

This document is organised into the following sections:

- Section 2 Bioretention systems
- Section 3 Wetlands
- Section 4 Grass swales and buffer strips

Melaleuca viridiflora

Eucalyptus miniata

2 Bioretention Systems

Vegetation planted in bioretention systems need to tolerate condition where water ponds temporarily during rainfall but will drain relatively quickly after a rainfall event. The bioretention system will dry out completely during the dry season and vegetation thus needs to be able to withstand long periods of drought with minimal water requirements during the dry season.

The soils used in bioretention systems are highly permeable, free-draining and retain minimal water. Consequently, the plants used in these systems should be adapted to sandy, free-draining soils. In the wet-dry tropics, plants which are typical of savannah ecosystems, open woodlands or forests, growing on sandy soils are likely to be potential species suited to bioretention systems. Vegetation which is also found in sandy riparian zones may also be suitable.

2.1 Density

Bioretention systems need to be planted with sufficient density to ensure sufficient biological processing of nutrients and active growth in the upper layers of the filter media. Typical overall densities of vegetation are a minimum of 6 plants per square metre with densities of 8 plants per metre recommended. Higher planting densities are also suitable, but increase the cost of planting.

2.2 Planting Stock and Form

Planting should incorporate several growth forms – trees, shrubs, tufted plants and groundcover species, to ensure that the plant roots occupy all parts of the media. It is recommended to plant either shrubs or small to medium trees within bioretention systems where possible. Trees are able to provide shade, higher evapotranspiration rates, deeper rooting depths and a degree of local climate control.

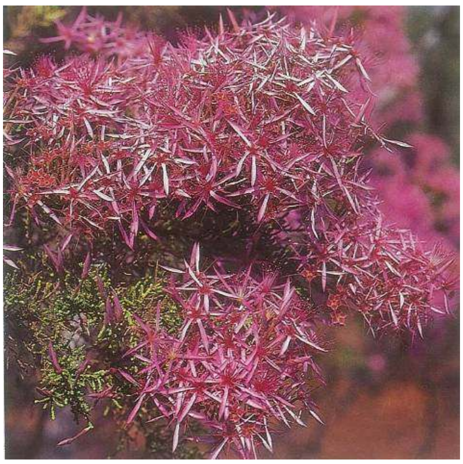
In general it is recommended to plant a mixture of species within a bioretention system. A range of species provides reduced risk of failure of all the vegetation if a particular species is not suited to the microclimate. Using several species reduces the risk that insect attack, disease or adverse weather will harm all of the plants at once.

Bioretention systems will commonly comprise a minimum of five to ten species, depending on the size and hydrologic conditions within individual systems. In general larger bioretention systems will have more species than smaller bioretention systems.

2.3 Indicative Species List

This list of species is indicative only, and the advice of a WSUD professional and/or ecologist should be sought to guide the selection of vegetation for the particular microclimate and hydrologic regime of the bioretention system. The exact location within the bioretention system, species mixes and planting densities require a considered selection based on availability and cost to ensure optimal treatment performance.

Boronia lanuginosa



Calytrix exstipulata

Table 1: Indicative Species List for Bioretention Systems

Scientific Name	Common Name	Type of Plant	Maximum Height
Bioretention Media - Trees on sandy media			
Eucalyptus miniata	Woollybutt	Tree	8-20
Eucalyptus tetradonta	Stringybark	Tree	10-30
Melaleuca dealbata	Paperbark	Amphibious tree	12
Melaleuca viridiflora	Paperbark	Amphibious tree	12
Pandanus spiralis	Screw palm	Amphibious tree	10
Bioretention Media - Shrubs on sandy media			
Boronia gradisepala		Shrub	0.5
Boronia lanuginosa		Shrub	0.5-1.5
Bossaiea bossaioides		Shrub	1-2
Calytrix exstipulata	Turkey bush	Shrub	1-4
Grevellea pungens		Shrub	1-1.5
Grevillea angulata		Shrub	1-4
Jacksonia dilatata		Shrub	2-4
Templetonia hookeri		Shrub	1-3
Verticordia cunninghamii		Shrub	1.5-5
Bioretention Media - understorey on sandy media			
Grevillea formosa		Shrub	0.5
Imperata cylindrica	Blady grass	Shrub	1
Platyzoma microphyllum	fern	Shrub	0.15-0.5
Cynodon dactylon	Couch	Grass	0.6
Isoetes coromandelina	Quillwort	Amphibious fern	0.8
Sorghum plumosum		Grass	
Sorghum stipodeum		Grass	
Extended Detention Area/Upper Batter Trees on clay soils			
Melaleuca dealbata	Paperbark	Amphibious tree	12
Melaleuca viridiflora	Paperbark	Amphibious tree	12
Extended Detention Area/Upper Batter - Understorey on clay soils			
Cyperus scariosis	Sedge	Amphibious sedge	0.8
Fimbristylis dichotoma	Sedge	Amphibious sedge	1
Isoetes coromandelina	Quillwort	Amphibious fern	0.8
Extended Detention Area Upper Batter (terrestrial vegetation)			
Eucalyptus miniata	Woollybutt	Tree	8-20
Eucalyptus tetradonta	Stringybark	Tree	10-30
Sorghum plumosum		Shrub	
Sorghum stipodeum		Shrub	
Themeda australis	Kangaroo grass	Grass	0.75

3 Wetlands

Vegetation plays an important role in the function of the stormwater treatment wetland. This functional role differs for different zones within the wetland, and the species chosen for each zone perform specific tasks.

Natural systems provide important guidance on the design of constructed wetland systems, particularly in relation to the hydrological regime of wetlands, vegetation types and their adaptations and vegetation communities and vegetation communities. More detail on this is provided in Appendix A.

The wetland will have three major components

- an area of permanent deep open water, that retains water throughout the year, and draws down considerably during the dry season
- a seasonally inundated zone that will dry out during the dry season, but will retain a permanent pool water during the wet season
- bunds to promote even distribution of flow throughout the wetland

The sections below summarise the attributes of species chosen for the different zones. Table 2 lists examples of the types of plants proposed for each zone with the attributes upon which their selection was based.

3.1 Permanent Pool

Submerged aquatic plants were chosen for the following properties:

- Tolerance of deep water
- Habitat for aquatic fauna including mosquito predators

Emergent macrophytes were chosen for the following properties:

- Growth habit – thin, tall, firm stems to provide a large surface area for colonisation by microbial and algal biofilms
- Dense clustered growth form with spiky stems to discourage pedestrial traffic
- Aesthetic appeal

3.2 Seasonally Inundated Zone (SIZ)

Emergent macrophytes were chosen for the following properties:

- Ability to survive periodic dry spells of up to 2 months duration
- Tolerance of regular inundation of up to 1.1m
- Growth habit – thin, tall, firm stems to provide a large surface area for colonisation by microbial and algal biofilms
- Aesthetic appeal

3.3 Bunds

Emergent macrophytes were chosen for the following properties:

- Tolerance of seasonal dry spells
- Tolerance of seasonal inundation of 0.1m for extended periods and up to 0.6m for short periods

3.4 Batters

Emergent macrophytes were chosen for the following properties:

- Tolerance of seasonal dry spells

- Tolerance of seasonal inundation of 0.1m for extended periods and up to 0.6m for short periods

The batters can be planted with annual species that grow either in shallow water during the wet season or that establish on the drying batters during the dry season.

3.5 Indicative Species List

This list of species is indicative only, and the advice of a WSUD professional and/or ecologist should be sought to guide the selection of vegetation for the particular microclimate and hydrologic regime of the wetland. The exact location within the wetland, species mixes and planting densities require a considered selection to ensure optimal treatment performance.

Table 2 Indicative species list for stormwater treatment wetland zones

Scientific Name	Common Name	Type of Plant	Height (m)	Exposure Tolerance	Inundation - Depth (m)	Inundation Duration (months)
Permanent Pool - Permanently wet emergent macrophytes						
Actinoscirpus grossus		Tall Rush	3	Nil	1 ?	12
Eleocharis sphacelata	Tall Spikerush	Tall Rush	2	Low	1.5	12
Lepironia articulata		Tall Rush	4	Nil	1.5	12
Schoenoplectus littoralis		Tall Rush	2	Low	1 ?	12
Permanent Pool - Permanently wet submerged macrophytes						
Ceratophyllum demersum	Hornwort	Submerged Aquatic Herb	0.6	Low-Moderate	1-2	12
Myriophyllum dicoccum	Water Milfoil	Submerged Aquatic Herb	0.5	moderate	1-2	12
Najas tenuifolia	Water Nymph	Submerged Aquatic Herb	0.5	Nil	2	12
Vallisneria nana	Ribbonweed	Submerged Aquatic Herb	0.7	Nil	1	12
Potamogeton javanicus	Pondweed	Submerged Aquatic Herb	N/A	Low ?	1-2	12
Potamogeton tricarinatus	Pondweed	Submerged Aquatic Herb	M/A	Nil	1-2	12
Seasonally Inundated Zone						
Eleocharis sphacelata	Tall Spikerush	Emergent Macrophyte	2	Low	2	12
Pseudoraphis spinescens	Spiny Mudgrass	Emergent Grass	1-2	High	1	10

Phragmites australis	Common reed	Emergent Grass	5	High	1.5	9.5
Bunds - understorey						
Fimbristylis dichotoma	Sedge	Amphibious Sedge	1	High	0.5	6
Cyperus scariosis		Amphibious Sedge	0.8	High	0.5	6
Ischaemum australe		Amphibious Grass	1.5	High	0.5	6
Oryza australiensis	Native Rice	Emergent Grass	2.5	High	1	9 ?
Paspalum distichum	Water Couch	Amphibious Grass	0.6	High	0.5	6
Isoetes coromandelina	Quillwort	Amphibious Fern	0.8	High	0.5	6
Bunds - trees						
Melaleuca dealbata	Paperbark	Amphibious Tree	12	High	1	6
Melaleuca viridiflora	Paperbark	Amphibious Tree	2-16	High	1	6
Pandanus spiralis	Screw Palm	Amphibious Tree	10	High	1	6
Lower Batter (seasonally wet) - wet season						
Cyperus scariosis		Amphibious Sedge	0.8	High	0.5	6
Fimbristylis dichotoma		Amphibious Sedge	1	High	0.5	6
Schoenoplectus praelongatus		Amphibious Sedge	0.5	High	0.3	6
Lower Batter (seasonally wet) - dry season						
Coldenia procumbens		Herb	0.5	High	0.1	6
Phyla nodiflora		Herb	0.2	High	0.1	6
Sporobolus virginicus	Salt Couch	Grass	0.6	High	0.1	6
Cynodon dactylon	Couch	Prostrate grass	0.2	High	0.1	6
Glinus oppositifolius		Herb	0.5	High	0.1	6
Upper Batter (terrestrial vegetation)						

Sorghum plumosum		Grass	0.7-3m	Moderate	0.1	
Sorghum stipodeum		Grass	1-3m	Moderate	0.1	
Themeda australis	Kangaroo grass	Grass	0.75	High	0.1	
Eucalyptus papuana	Ghost Gum	Tree	8-15	High	0.1	
Eucalyptus polycarpa		Tree	10-15	High	0.1	

4 Swales and buffer strips

A key consideration in selecting vegetation for swales is the need for flow conveyance. Vegetation selection needs to be considered in the hydraulic modeling of the swale. If the swale is to function as an open conveyance channel as its primary purpose, then dense vegetation is generally avoided. Turf species with trees may be appropriate in some situations, although consideration needs to be taken of the shade tolerance of turf species when planting trees

Where water quality is a key consideration native vegetation, including tufted perennials, dense shrubs and/or trees, is generally preferred. The use of native vegetation is more effective at providing stormwater quality treatment than turf grasses, although for a given cross section channel native vegetation swales area able to convey less stormwater than a turf lined swale. Swales planted with native vegetation are effective in limiting vehicular or pedestrian access to the swale surface if desired.

All swales should be constructed with a layer of good quality appropriate topsoil to support vegetation.

4.1 Turf

Species selected for turf need to be tolerant of mowing and some traffic. The turf grasses listed are selected to be relatively tolerant to weeds and have been used successfully as turf grasses in Darwin. These species are commercially available, typically reproduced vegetatively.

This is an indicative species list for planting in swales and buffer strips. During a project's detailed design specialist advice should be sought regarding the performance of these species under the specific conditions of the site and selection should also reflect the desired maintenance regime.

- *Axonopus compressus* (Carpet Grass)
    - Is recommended to be used in high shade situations only due to it's tolerant to shade especially after established. Carpet grass requires irrigation during the dry season as it will not respond well to drying out and then inundation after rain. Carpet grass requires sandy soils which are moist and hence well irrigated during the dry season.
- *Cynodon dactylon* (Green Couch)
    - Is a widely distributed warm season turf grass and is well suited to swales due to its tolerance to wet conditions including periods of temporary inundation. Green couch is best suited to sandy loam soils. Couch is however a relatively high maintenance turf with requirements for insecticide application and fertiliser.
- *Digitaria didactyla* (Blue Couch)
    - This is the most common turf species in Darwin and is suitable for well drained sandy loam soil swales. Blue Couch is a high maintenance turf which requires regular irrigation, some fertiliser application, and is susceptible to predators. Blue couch is also not well suited to shady locations.
- *Microlaena stipoides var. stipoides* (Lawn grass)
- *Paspalum notatum* (Bahia Grass)
    - Suitable for a wide range of soil types including sands and is tolerant to moderate inundation. It has a deep and extensive root system and can survive periods of drought. The grass is able to survive without irrigation during the dry season and responds quickly to rainfall which is important to protect the soil from erosion during the early rain periods. It is widely used for this reason on roadsides.
- *Stenotaphrum secundatum* (Buffalo Grass)
    - Is a suitable grass for swales due to its tolerance to short term flooding. Buffalo grass is a tropical and warm temperate grass which requires watering during the prolonged dry season. Buffalo grass is also moderately tolerant of shade.
- *Zoysia matrella* (Manila Grass)
    - Is suitable in swales which have underdrainage as Manila grass is not suitable on wet soils. Manila grass is drought tolerant and is tolerant of high temperatures, moderate shade and high use. Manila grass is low maintenance, especially after it is established.

4.2 Native Vegetation

A wide range of native vegetation will be suitable. It is recommended to use the species list provided in Table 1 as a starting point for the selection of vegetation although other vegetation may be appropriate depending on the exaction site requirements.

5 REFERENCES

The vegetation list developed in this guideline was guided and informed by:

- *Freshwater aquatic plants of Darwin Harbour catchment*, Cowie ID, Proceedings of the Darwin Harbour Public Presentation, 2003
- *Vegetation Communities of five Magela Creek billabongs, Alligator Rivers Region, Northern Territory*, Finlayson CM, Thompson K, von Oertsen I, and Cowie ID, Technical Memorandum 46, 1994
- *A compendium of information for managing and monitoring wetlands in tropical Australia*, Finlayson CM and Spiers AG (eds), Supervising Scientist Report 148, 1999
- *Plant Ecology of Australia's Tropical Floodplain Wetlands: A Review,* Finlayson CM, Annals of Botany, 96 (4), 2005
- *Suitable Lawn Grasses for the NT: Agnore*, Cameron AG, 2006
- *Variation in the composition and structure of tropical savanna as a function of rainfall and soil texture along a large-scale climatic gradient in the Northern Territory Australia*, Williams RJ, Duff GA, Bowman, DMJS, Cook GD, Journal of Biogeography volume 23, 1996
- *Wetlands in the arid Northern Territory*, Duguid A, Barnetson J, Clifford B, Pavey C, Albrecht D, Risler J and McNellie M, 2005
- Native plants of Northern Australia, Brock J, 2001
- *Floodplain Flora: A Flora of the Coastal Floodplains of the Northern Territory, Australia*, Cowie ID, Flora of Australia Supplementary Series 10, 2000
- How to Create a Waterwise Garden in the Top End, PWC and NGINT, 2008
- *FloraBase: the Western Australia Flora*, Department of Environment and Conservation Western Australia Herbarium, available online at http://florabase.calm.wa.gov.au/

Appendix A

1.1 General Aquatic Plant Ecology and Typology

Research conducted on two of the key aquatic systems of the Northern Territory, namely the Alligator, Daly and Mary River floodplains and the freshwater lagoons of the Darwin region have identified that the aquatic ecosystems of the wet-dry tropics typically consist of a number of different zones. They are classified according to whether they remain permanently wet during the year and general water depth. These zones vary in vegetation and width depending on local site conditions. These vegetation zones can generally be described as:

- Dry fringe - A fringe of woodlands including Melaleuca spp, *Pandanus* spp and *Barringtonia* spp along the margins.

- Seasonally inundated areas - a mixture of grasses and sedges shaded by woodlands in seasonally flooded areas grading from 0.2m deep to grass species that are up to 1.5m in the wet season.

- Fringe permanently inundated - A ring of submerged species, including water lilies and submerged plants that are permanently inundated. Typically this area is restricted to a narrow belt around edge of the open water.

- Permanently open water - An area of open water in the centre of the floodplain or lagoon. This area of open water can sometimes be replaced with floating mats, of free floating aquatic plants.

A cross section of an idealised section through a floodplain wetland (modified from Cowie, 1999) is shown in Figure 2. This cross section shows the water levels during the mid-wet and late-dry seasons with likely species composition during the mid-wet season. The seasonally inundated species shown include *Oryza, Hygrochloa* and *Pseodoraphis* spp. The fringe permanent species include *Nymphoides* and *Nymphaea* spp. Figure 3 shows the East Alligator River floodplain during the wet season, and it includes open water, shallow water vegetated with grasses and sedges, and fringing melaleuca woodland.

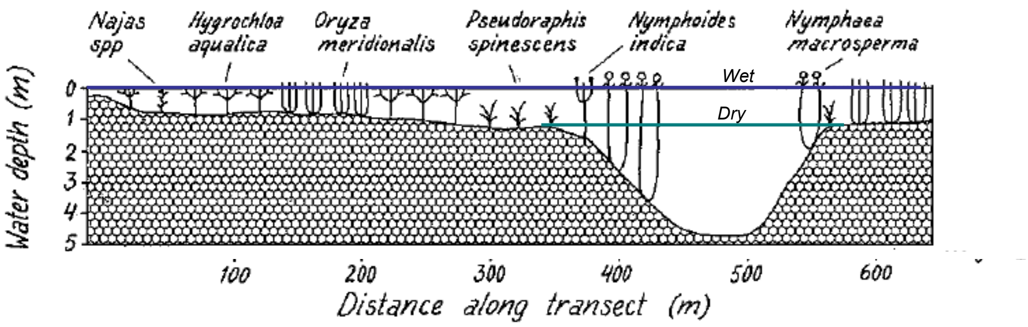


Figure 2: Idealised Cross Section through Aquatic Ecosystem (modified from Cowie, 1999)

Figure 3: Image of East Alligator River Floodplain during the wet showing an open water zone in foreground to fringe melaleuca zone in background

1.2 Vegetation

The composition of vegetation in aquatic ecosystems changes continually between seasons and from year to year. The most obvious change is the variation from the wet season to the dry season. During the wet season emergent macrophytes flourish in water depths less than 1m and cover the floodplains and lagoons. During the dry season these zones typically dry out completely and are replaced with sparse, scattered terrestrial annual and reduced aquatic perennial grasses and herbs. Figure 4 illustrates this seasonal pattern for three key species which dominate during the wet season but which either survive in a significantly reduced dry-land form during the dry season, or survive as a seed and die off completely. The figure shows measurements of biomass compared to water depth over a year and illustrates how different species dominate at different times during the wet season, from early wet season through to late wet season.

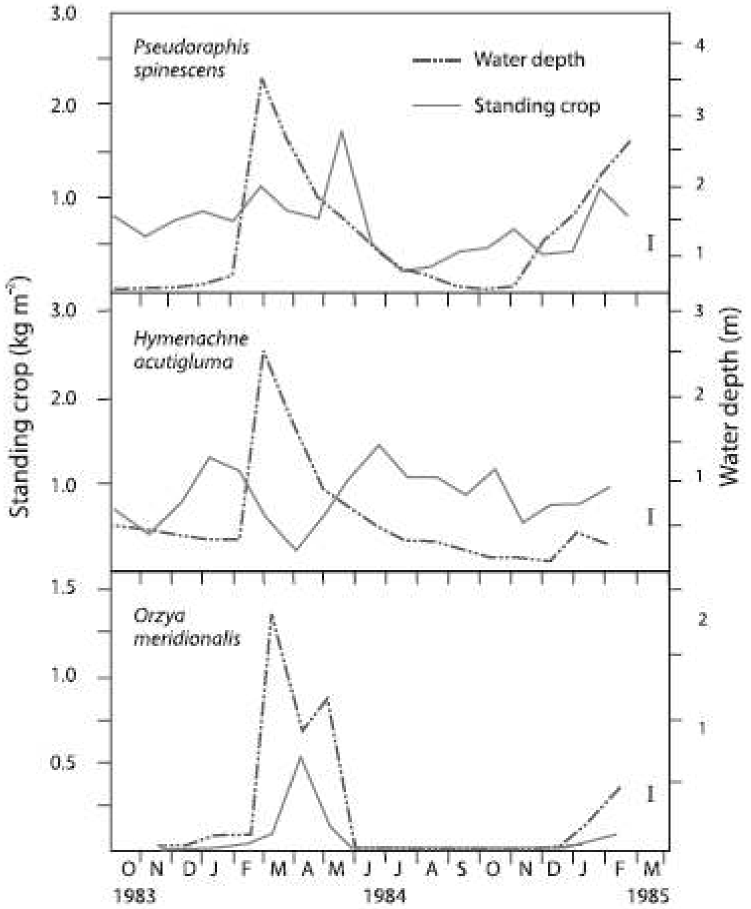


Figure 4 Biomass during the wet season and dry season (Finlayson et al, 2006)

Vegetation can be categorised into distinct groups based on how it has evolved to survive the alternating wet season and dry season:

- Dry land annuals which are sparsely distributed and occur almost exclusively through the dry season and include species 'mud flat species' such as *Glinus oppostifolius Cyperus digitatus,* and *Phyla* spp. These species survive the wet season as seeds and germinate on wet soil at the beginning of the dry season. Some species require a period of burial in wet mud before they will germinate.

- Wet season annuals which occur almost exclusively through the wet season and include species such as *Oryza meridionalis*, *Maidenia rubra* and*Najas* spp. These plants survive as seed or spore during the dry seasonand complete their cycle as during the flooded season.

- Plants which survive through vegetative reproduction with underground tubers (eg , *Eleocharis* spp and *Triglochin dubium*)) underground corms (eg *Crinum angustifoium)* and thickened rhizomes (eg *Lepironia articulata*).

- Seasonal perennials which are seasonally inundated but present during the dry season, often in the xerophyctic or dry-land form. They include species such as *Pseudoraphis spinescens, Ludwigia adscendens, Phyla nodiflora* and *Hymenachne acutigluma*

- Permanent perennials inundated throughout the year. These include species dominated by water lilies such as *Nelumbo bucifera* and *Nymphoides indica* and floating grass mats species such as *Leersia hexandra* and *Phragmites vallatoria* and *Cyclosorus interruptus*.

The floodplain communities contain a high proportion (around 70%) of annual plants compared to other vegetation communities, aquatic and terrestrial.

1.2.1 Wetland and Floodplain Communities

The most common community type across the aquatic ecosystems, especially in the floodplains, is grassland dominated by wild rice (*Oryza* spp) with or without a Melaleuca forest overstorey. The grasslands are dominated by *Oryza meridionalis* which in the dry season dies off.

Other common communities include

- *Eleocharis* sedgelands which dominate during the wet season and are replaced by annual herbs during the dry season. *Eleocharis* spp are slower to establish and typically dominate during the middle to late wet season.

- Grasslands such as *Pseudoraphis* grasslands which are dominated by *Pseudoraphis spinescens* which has a turf like appearance during the dry season and grows up through the water during the wet season and *Hymenachne* grasslands which is dominated by *Hymenachne acutigluma* throughout the year.

- *Melaleucas* are common on the fringes of floodplains and lagoons. The understorey of the *Melaleuca* forests varies considerably is typically reflective of the interfacing floodplain grass communities. The presence of any individual species of *Melaleuca* appears to reflect the flooding depth and salinity tolerance. Melaleuca viridiflora tolerates the direst conditions and *Melaleuca leucadendra* the wettest. *Melaleuca cajuputi* is the most tolerant of saline conditions.

- *Floating Mats*: Rafts of aquatic free-floating plants, interlocked, upon which in their advanced form, semi-terrestrial plants establish. Floating mats can be many metres deeps, and more than 50m wide and can completely cover lagoons. Studies of Finiss River inear Darwin showed that zones had established within the floating mat including a zone of the sedge *Hymenochaeta grossa* with an understory of *Cylosorus interruptus*, a zone further from the shore included two grasses *Isachne globosa* and *Leersia hexandra* as well as *Cylosorus interruptus*. A similar zone further out from the shore included similar grasses and was underlain with a *Pistia stratiotes*.

1.2.2 Wetland Depth and Inundation Duration and Timing

Vegetation is strongly influenced by timing, duration and intensity of the wet season. Small differences water depth and inundation duration have major effects on the distribution of plant communities (Finlayson, 2005). The impact of small variations in depth and salinity are shown in Figure 5. The vegetation is also a function of both the flooding and drying regime of the aquatic ecosystem. It is also likely that plant establishment is dependent on the flow velocity (Morley, 1981).

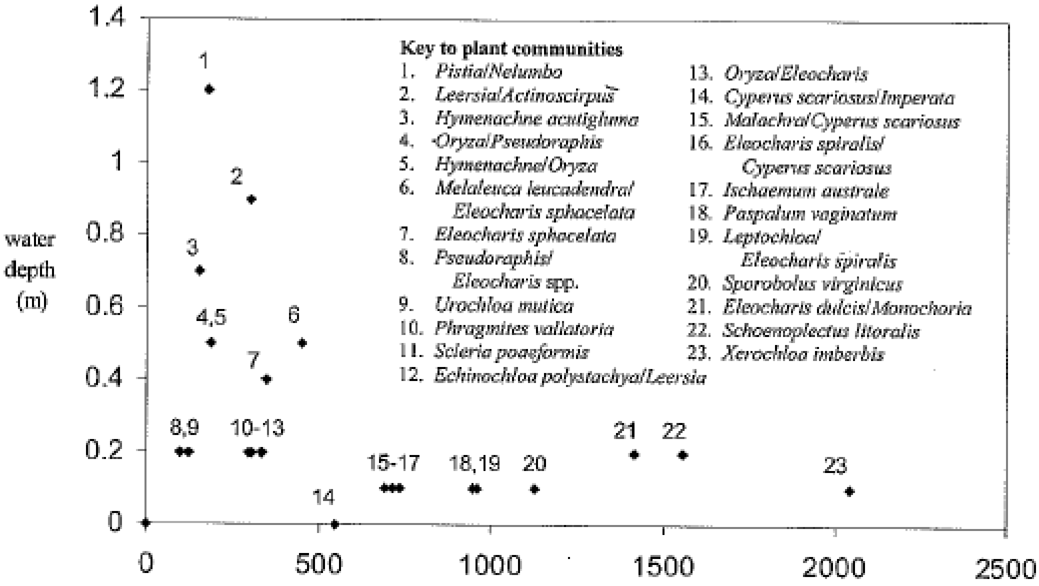


Figure 5 Salinity and flow depth relationship

The success of aquatic annual species is influenced by the pattern of storms and subsequent drying. For example rapid flooding resulting in high water levels at the beginning of the wet season is detrimental to the establishment of some emergent grasses and sedges. This has been shown in lab experiments on 'moist conditions' compared to 'flooded conditions' on seed germination of key emergent aquatic species (Finlayson, 1990) found that:

- Moist conditions favoured *Pseudoraphis spinescens*, *Hymenachne*, *Oryza* and *Eleocharis* spp
- Under flooded conditions *Oryza* and *Eleocharis* spp produced no seedlings at all
- Under the flooded treatment submerged aquatic species suchas *Utircularia* spp, *Najas* spp and *Maidenia rubra* were favoured

As Finlayson (1989) notes that once the surface water evaporates the most important environmental variable for plant growth is soil moisture. In natural systems soil moisture is positively correlated to the period of inundation. This is illustrated by *Pseudoraphis spinescens* which senesces after the soils dry out and by the late season was restricted to areas that had been inundated for more than 6 months.

1.3 Tropical Savanna Communities

Tropical savanna communities refer to woodlands or open forests of eucalypt trees, with an understorey of perennial and annual grasses. A savanna community dominated by *Eucalyptus miniata* and *sorghum* spp. is shown in Figure 6. Near the higher-rainfall coastal margins the tree canopy is regarded as an "open-forest". In the savanna communities there is significant light in the lower layers. Competing with the grassy layer are a variety of herbs and vines.

Tropical savanna communities have adapted to survive through the long dry season and the wet season. The adaptations include:

- Going into a dormant phase, surviving the dry season as seed or spores or underground tubers or by losing leaves.
- Obtaining moisture from the lower soil layers to remain evergreen. Recent research has identified that the tropical savanna do not necessarily have deep root systems (eg Werner, 2001, Fensham 1992) so it remains unclear how the savannas access moisture from the surrounding soil layers during the dry season.

Figure 6 ***Eucalyptus miniata*** **and** ***sorghum*** **spp woodland**

The most frequent dominant tree species of the overstory of the tropical savannas are the Stringybark Eucalyptus tetrodonta and the Darwin Woolly Butt E. miniata which are common on sandy and loamy soils. Ghost Gum E. papuana and Swamp Bloodwood E. polycarpa are often found on alluvial plains and adjacent to drainage lines, while Coolibah E. microtheca is the characteristic species of open woodlands in heavy clay soils in the southern savanna zone.

Evergreen canopy fullness shows little seasonal variation or variation in evapotranspiration (Eamus, 2000). Furthermore evergreen Eucalypt species account for more than 80% of the standing tree biomass and canopy cover in savannas in the Darwin region (Hutley, 2000).

Two studies which undertook root excavation to determine root depth have shown that roots were concentrated near the surface, although the decline with depth was less marked for large roots (eg Werner, 2001, Fensham 1992). Both studies found that the roots were predominantly in the top 1m of the soil. Fensham (1992) found that the morphology of roots was bimorphic, with 70% of biomass at <20-cm soil depth, and large roots running horizontally on top of the shallow (0.3–1.4 m) ferricrete layer with no evidence that roots had access to water below this layer.

The understory consists of predominatly evergreen semi-deciduous and deciduous small and shrubs trees which are patchily distributed. They include Acacia spp, *Eucalyptus* spp, *Jacksonia spp*, *Erythrina* spp palms, cycads, and include common species such as *Erythohpleum chlorostachys*, *Terminalia ferdinandiana, T. grandiflora , Xanthostemon paradoxus* and *Croton arnhemicus*.

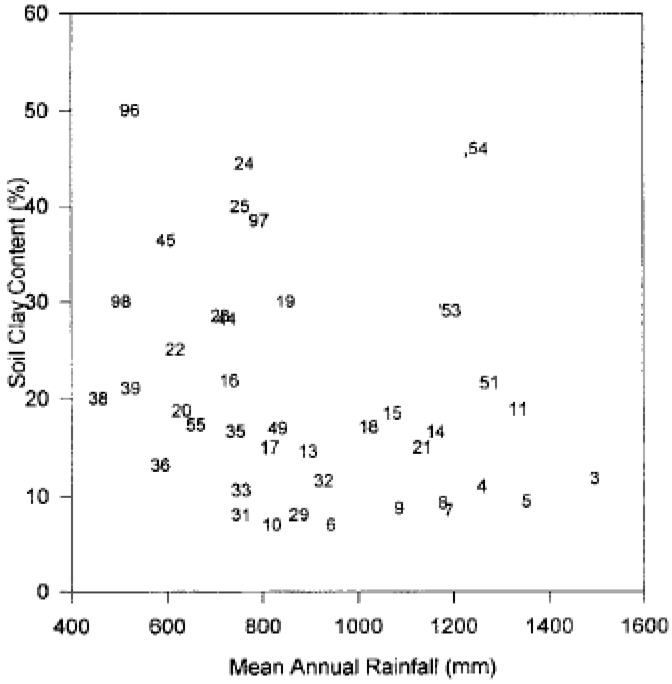
The grass communities are not necessarily closely associated with changes in tree composition. The grass communities are typically dominated by:

- annual Sorghum species which reach heights of 2.5m (about 12 species in all)
- perennial tussock grasses including *Sorghum plumosum*, *Chrysopogon fallax*, *Heteropogon*, *Aristida* or *Themeda Australis*;
- hummock grasses (particularly Curly Spinifex (*Plectrachne* pungens and *Triodia bitextura*).

Perennial grasses respond quickly to early storms and can respond with green shoots within days. On deep sandy soils Sorghum species can form monospecific stands. . Understory Leaf Area Index (LAI) changes dramatically over the wet season. Eamus (2001) showed in a study of savanna near Darwin that an understory dominated by Sorghum spp had a LAI of 2 to 3 in the wet season which reduced to 0.2 after the grasses senesces early in the dry season (late April) and understory LAI remained low throughout the dry season.

Studies on grass seed germination by Mott (1978) showed that common grass seeds of the savanna, such as *Themeda australis*, *Chrysopogon fallax*, *Sorghum plumosum* and *Sorghum stipoideum* require sufficient rainfall to reduce osmotic stress before the seeds germinate. To prevent early germination from unusual winter rains, grass seeds also have a 3 to 4 month dormancy period to ensure that they do not germinate during the dry season. Studies have show that germination rate during the early wet season is very high, in some cases over 90% of the total germination occurs after the first rains of the wet season. (Mott, 1978)

The composition and structure of the savanna is largely determined by the moisture and nutrients available to the plants, and this depends on rainfall, topography and properties of the soil. This is shown in Figure 7. The key community species for the Darwin Region are 3 (*E. minicita* and *E. tetrodonta* and *E. nesophila* open forest), 4 (*E. minicita* and *E. tetrodonta* open forest), 5 *E.* m*inicita* and *C. intratropica)*, 11(*E. minicita* woodland), 51 (M.viridiflora and *E.* spp open forest) and 54 (mixed grasses and sedges). These areas are the areas of highest rainfall (> than 1200mm).



(b) **Direct Gradient Analysis - Structural Classes**

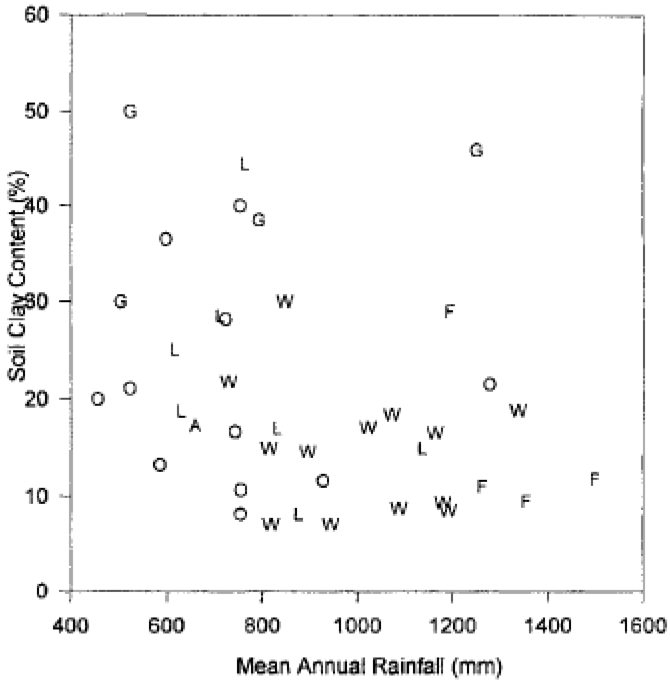


Figure 7 Community types based on rainfall and soil clay content (F= forest; W = woodland O=open woodland, L=low open woodland A=Lancewood-woodland G= grassland) (Williams, 1996)