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WATER SENSITIVE URBAN DESIGN

STORMWATER TREATMENT OPTIONS FOR DARWIN DISCUSSION PAPER

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

The aquatic environment of the Darwin Harbour provides many key uses and values for the community of Darwin (Water Monitoring Branch, 2005). It is a recreational resource, provides significant amenity to the region and underpins economic activity. Importantly the harbour represents the key aquatic ecosystem of the region providing habitat for a range of estuarine and freshwater flora and fauna. For example 27,350ha of mangrove forest is found in Darwin Harbour which constitutes approximately 5% of the total mangrove area of the Northern Territory.

The Harbour is the ultimate receiving environment for all stormwater and wastewater discharge from Darwin and Palmerston urban areas, which support a population of approximately 110,000 people. Recent research has identified that although the harbour is considered to be in pristine condition with good water quality, the impacts of urban stormwater runoff and wastewater discharges are evident. Wastewater discharges are resulting in localised degradation within the estuarine tributaries of the harbour and during the wet season, stormwater runoff from urban areas is resulting in high loads of sediments, nutrients and heavy metals entering local waterways.

Current predictions for 2050 are that the Darwin Harbour region will experience strong population growth with an expectation of the need for an additional 50,000 to 100,000 new dwellings over this period. Given these large development pressures facing the Darwin Region, and the potential impact this will have on these pristine receiving systems within Darwin Harbour, the Territory has identified that a coordinated strategy is required for managing the Harbour.

In this regard, Darwin Harbour Regional Plan of Management and the Draft Stormwater Management Strategy for the Darwin Harbour Catchment establishes the initial elements of a framework for managing the water quality impacts to the Harbour. Additionally, a Water Quality Protection Plan (WQPP) is being developed for Darwin Harbour Catchment. The WQPP is a jointly funded project with the Australian Government, through the Coastal Catchments Initiative (CCI), aimed at identifying and addressing key water quality risks to the values of the Darwin Harbour and its catchment. The WQPP is being developed over a three year period and the Department of Natural Resources, Environment and the Arts (NRETA) has primary responsibility for the development of the plan.

In order to manage the impacts to Darwin Harbour, particular from new development and re-development areas, the Territory has identified that the implementation of water sensitive urban design (WSUD) on all new development zones is critical. To assist in the adoption of WSUD, the Department of Planning and Infrastructure in conjunction with NRETA (Department of Natural Resources and Environment) have secured a grant from the commonwealth Coastal Catchments Initiative (CCI) program to develop a **WSUD Strategy for Darwin Harbour**. The Strategy is to create an enabling environment to ensure commitment to water cycle and stormwater management through the development of a WSUD framework linking policy to locally relevant technical design guidelines, manuals and industry tools. Development of the Strategy represents a substantial project as defined by the Workplan provided in Table 1 below.

This discussion paper has been undertaken as part of Task 5 of the Workplan and will ultimately inform Tasks 15 and 16 of the Workplan. The paper provides commentary on the technical issues associated with managing stormwater in the wet-dry tropics of the Darwin region and presents potential stormwater treatment solutions in response to these issues. The paper is provided to initiate discussion of stormwater treatment options as part of proposed future workshops.

Table 1: WSUD Strategy for Darwin Harbour - Workplan

#	TASK	OVERARCHING ACTIVITIES							
		Project Management & Coordination	Communication & Consultation	Identifying & Overcoming Barriers to WSUD Adoption	Identifying WSUD Design Objectives	Developing a WSUD Policy & Planning Framework	Developing WSUD Guidelines & Tools	Developing Case Study Examples of WSUD	Developing a Implementation Strategy
1	Refine workplan								
2	Establish project working group.								
3	Develop WSUD Strategies for case studies in suitable format for communication and identify case studies for sub-catchment scale application of WSUD treatment train. • WSUD Showcase - Bellamack residential sub-division conceptual WSUD Strategy is complete • Design development of Bellamack WSUD Strategy is about to commence (see Task below)								
4	Identify potential WSUD objectives for Darwin • Stakeholder workshop held on 14th and 15th June 2007 WSUD Objectives for Darwin – Discussion Paper (EDAW, Oct 2007)								
5	**Critical Analysis of WSUD/Stormwater Treatment Options for Darwin** • **Stakeholder workshop held on 14th and 15th June 2007** • **Water Sensitive Urban Design Stormwater Treatment Options For Darwin - Discussion Paper (EDAW, Oct 2007)**								
6	Prepare a stakeholder communication and consultation strategy (including establish website, fact sheets, presentations).								
7	Prepare and communicate a definition of WSUD within Darwin								
8	Review and report on policy, programme, technical and decision-support systems for WSUD in Australia (including any barriers to uptake of WSUD and respective jurisdictional responses).								
9	Identify potential barriers to uptake of WSUD in the NT. Develop strategy to address barriers.								
10	Develop WSUD Strategies for case studies in suitable format for communication and identify case studies for sub-catchment scale application of WSUD treatment train. • WSUD Showcase – Complete design development of the Bellamack WSUD Strategy • Identify and scope work associated with “retrofit” WSUD case study								
11	Prepare detailed workplan for development of NT WSUD policy, objectives, design manual, performance standards and decision-support tools.								
12	Prepare draft NT WSUD policy and objectives for Darwin including understanding existing legislation, workshops etc.								
13	Assess application of WSUD objectives and management practice options across a range of development situations and/or catchment-scale treatment-train & confirm set of objectives.								
14	Undertake consultation of draft WSUD policy and WSUD objectives to stakeholders and barriers to WSUD.								
15	Define requirements of WSUD Guidelines and Tools (workshop to define design needs in detail and assess whether exiting guidelines satisfy this need)								
16	Document Draft WSUD Guidelines and Tools in including High Level and Conceptual Design Guideline, Technical Design Guideline and Design Tools (MUSIC Guidelines, Deemed to Comply Solutions, Standard Drawings etc.)								
17	Prepare Draft WSUD decision support tools for Darwin Harbour, consistent with WQPP, linking policy, objectives and guidelines								

18	Undertake stakeholder consultation of WSUD Policy, WSUD design manual and performance standards, and decision support Tools and seek approval.								
19	Finalise WSUD design manual, decision support tools and performance standards								
20	Seek NT Government approval for WSUD Policy, WSUD design manual and performance standards and decision support tools.								
21	Develop and publish stormwater management plans for key subcatchment in Darwin to illustrate application of WSUD Policy/Framework, design manual and decision support tools.\								
22	Develop an implementation strategy for incorporating policies and provisions for WSUD within NT planning policies, strategic plans and development approval processes as well as local government instruments\								
23	Ongoing communication and website management								
24	Capacity Building and Training including government, local authorities, developers and industry practitioners								
25	Incorporate policies and provisions for WSD into NT government planning policies, strategic plans and development approval processes, as well as relevant local government instruments. Implement agreed strategy to address barriers to uptake of WSD.								

1.1 Water Sensitive Urban Design

WSUD represents a new paradigm in the planning and design of urban development that aims to minimise impacts on the natural water cycle and protect the health of aquatic ecosystems. WSUD promotes the integration of the urban water streams, namely stormwater, water supply, sewerage management and groundwater, centred on delivering sustainable water cycle solutions.

Additionally, WSUD aims to integrate these urban water cycle solutions into the planning and design of the layout (buildings and landscapes) of an urban development, towards an overall goal of ecologically sustainable development (ESD), as illustrated in Figure 1. Further description of the philosophy and implementation of WSUD is provided in Australian Runoff Quality (Engineers Australia, 2005).

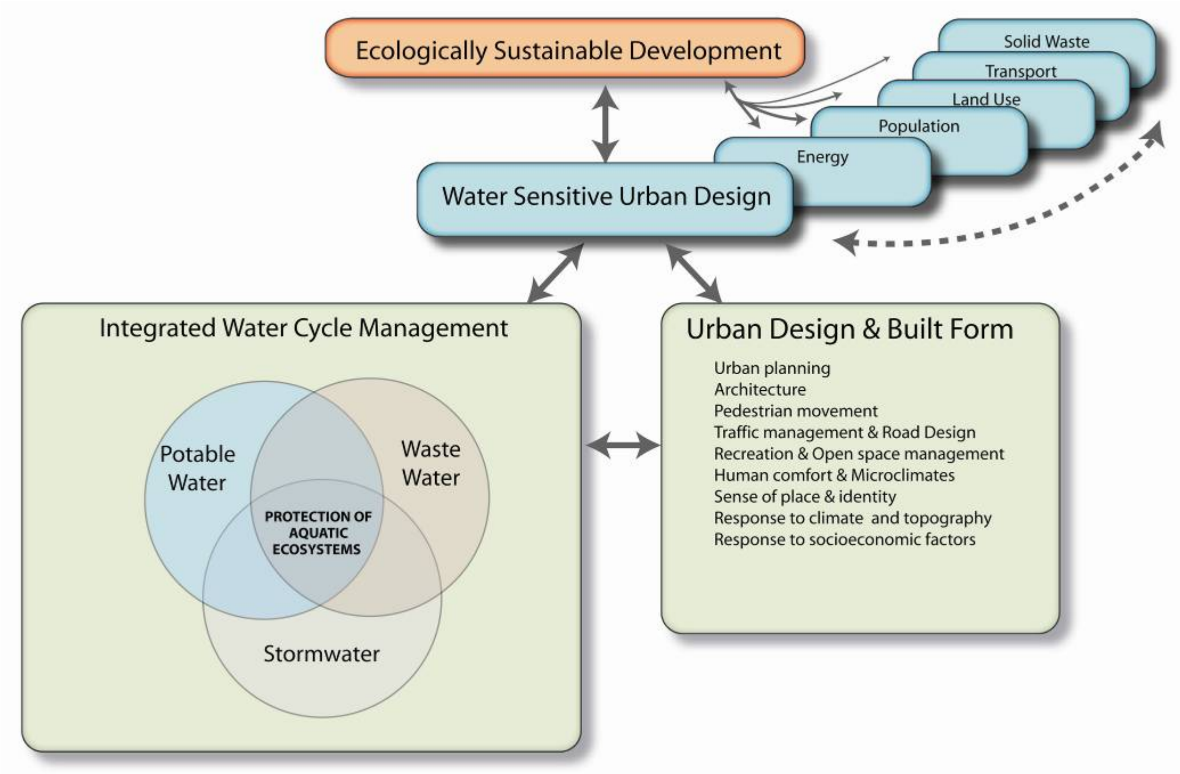

Figure 1 Relationship between water sensitive urban design, ecologically sustainable development and integrated water cycle management

To effectively implement WSUD into individual allotments, streets, suburbs and even master planned communities, water cycle management considerations should be incorporated into the planning and design process as early as possible. Additionally the conceptualisation of WSUD elements, particularly stormwater management elements needs to respond to the natural attributes of the site, region and receiving environment. The wet-dry nature of Darwin climate means close consideration must be given to conceiving stormwater management elements.

1.2 Stormwater Treatment Techniques (This Document)

This document is a discussion paper which focuses on potential stormwater treatment options for the Darwin Region. It presents some potential stormwater treatment solutions and discusses the issues involved in designing these systems in a wet-dry tropical environment. It is a discussion paper which will inform the next steps in conceiving the stormwater treatment systems for the Darwin Region. These steps include:

- A workshop with local ecologists and engineers to refine design options

- Workshops with local planners, urban designers and landscape architects to consider how stormwater treatment systems can be integrated into the urban design typical of the Darwin Region

- Further research on specific design solutions

- Implementation and testing of pilot-scale systems

This document will inform design guidelines and tools for stormwater treatment measures. In particular this document focuses on vegetated stormwater treatment measures including swales, wetlands and bioretention systems, which are central to WSUD. These types of systems are commonly used for stormwater treatment in subtropical and temperate regions in Australia, however in those regions they have been designed for a climate with more regular rainfall.

In the wet-dry tropics of the Darwin Region, the nature of the climate strongly influences the design of stormwater treatment measures particularly vegetated systems. Bioretention systems and wetlands will need to be able to tolerate long periods of dry weather, where they receive little or no inflow, as well as periods of heavy rainfall and high inflow. To date, there are only a few examples where vegetated stormwater treatment systems have been constructed in Australia's tropical urban areas.

This document presents a summary of:

- Temperate and sub-tropical stormwater technique design

- Key design considerations for stormwater treatment design in the wet/dry tropics

- Preliminary conceptual designs of treatment systems for the wet/dry tropics

Key components to understanding the function and modified design of stormwater treatment systems are examined in Sections 2 and 3 of this discussion paper. These components include:

- Hydrology of the Darwin region

- Stormwater pollution characteristics

- Plant ecology of the Darwin region

Sections 4 to 7 discuss stormwater treatment measures including swales, wetlands, bioretention systems and infiltration.

1.3 How to Provide Feedback on this Paper

Questions and feedback on the content of discussion paper should be forwarded in writing to:

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Comments are requested by 30th November after which selected direct consultation will occur (i.e. phone discussions and face to face meetings).

2 Stormwater characteristics

Contemporary stormwater management design responds to the specific characteristics and conditions of a site, the local and regional receiving environments and relevant water and landuse planning. The following sub-sections outline the stormwater quality and quantity characteristics which influence the design of stormwater treatment measures in the Darwin Region.

2.1 Climate

The Darwin Region is in the wet-dry tropics, which has distinct wet and dry seasons. The wet-dry tropics have been broadly defined as a region with rainfall between 600 and 1,600 mm, spread over 4-7 months of the year (Finlayson, 2005). Annual average rainfall for Darwin Airport (Bureau of Meteorology, 2007) and the estimated potential evapo-transpiration (PET) for the Darwin Region are shown in Figure 2.

Most of the rainfall in the Darwin Region occurs between November and March, with very little rainfall between April and October. The longest available rainfall record in the region is from Darwin Airport, where the average annual rainfall is 1705 mm/year. Temperatures in the region are high throughout the year, leading to relatively high evaporation in all months (the mean daily evaporation at Darwin Airport is 7.1 mm/day). Potential evapo-transpiration (PET) is a measure of the transfer of water to the atmosphere from both vegetated and unvegetated land surfaces. PET depends on climate, water availability and vegetation, and PET in the region is highest in the wet season.

Rainfall can vary substantially from one year to the next. The mean annual rainfall at Darwin Airport ranges from approximately 1,000 to 2,600 mm/year (Haig and Townsend, 2003). Across the region, rainfall is slightly higher at the coast compared to inland areas, however the number of rain days is relatively constant at 80-90 days/year.

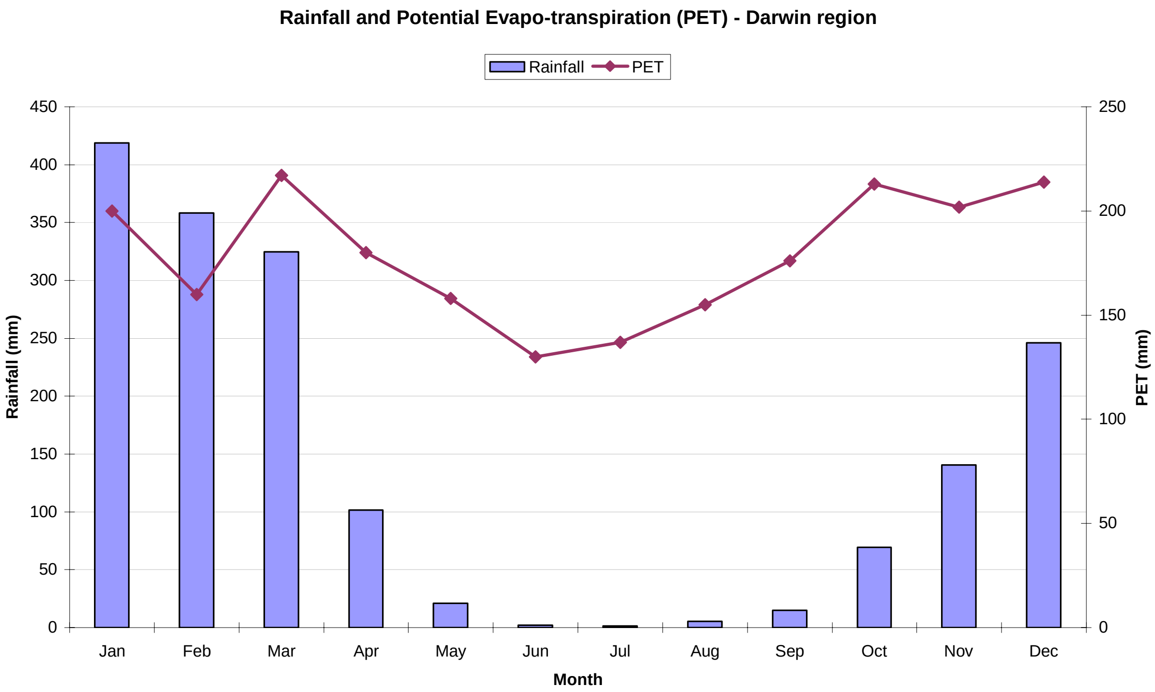


Figure 2: Average climate data for the Darwin Region

Table 2 describes six seasons of the wet-dry tropics in terms of rainfall and streamflow characteristics. The seasons are based on an indigenous calendar from Kakadu National Park.

Table 2: Seasons in the wet-dry tropics (adapted from Finlayson, 2005)

Time of year	Indigenous seasons		Rainfall and streamflow
January	Gudjeweg	Monsoon season	Consistent rain - creek flow inundates floodplain
February			
March			
April	Banggerreng	Harvest time	Rain ceases and water levels fall
May	Yegge	Cool weather	Flow ceases and floodplain dries
June			
July	Wurreng	Early dry season	
August			
September	Gurrung	Hot dry season	
October	Gunumeleng	Pre-monsoon season	Floodplain dry
November			Intermittently heavy storms
December			Consistent rain - creek flow inundates floodplain

2.2 Hydrology

Surface water runoff is governed by the seasonal patterns described above and as a result most streams in the Darwin region are ephemeral (i.e. dry out during the dry season). During the first part of the wet season, until December or January, most of the rainfall contributes to satisfying the soil moisture deficit, and runoff is limited. Streamflow commences around December or January, peaks over the wet season and then continues until around June (Haig and Townsend 2003).

Streamflow includes both baseflow, fed by groundwater discharge, and surface runoff. During the wet season surface flow dominates with up to as much as 80% of rainfall being converted to surface runoff, as many soils become waterlogged and cannot accept any additional infiltration.

During the dry season, streamflow is largely derived from baseflow which in most streams does not persist through the the entire dry season.

Annual runoff coefficients vary widely depending on land use:

- In undisturbed catchments they are as low as <10% to 30%
- In rural areas they range from around 30% to 50%
- In urban areas, they can be as high as 80%, or more than double the natural condition.

As well as increasing the volume of surface water runoff, urban development increases runoff frequency, magnitude and duration. This has significant ecological impacts, as flows reach erosive velocities more often, causing scour and erosion, altering physical habitat and washing out flora and fauna. It has been estimated that of the total fine grained sediment load transported by rivers

and creeks into Darwin Harbour, around 80% is derived from stream channel erosion, while only around 20% is derived from hillslope erosion (NRETA, undated).

It is thought that urban development may also increase the frequency of runoff events prior to the commencement of seasonal streamflow (i.e. additional runoff events may occur in November-December) (Haig and Townsend 2003).

2.3 Stormwater Quality

2.3.1 Stormwater pollutant processes

Our understanding of stormwater quality characteristics is improving, and current knowledge is summarised in *Australian Runoff Quality* (Wong, T H F (Ed) 2006). One of the most important factors in stormwater quality is catchment impervious fraction. Impervious surfaces generate additional runoff volume, and this carries additional pollutant loads. Direct connection of impervious surfaces to receiving environments via concrete pipes and channels also contributes to poor stormwater quality by conveying pollutants rapidly.

Buildup is a process of dry deposition of pollutants on impervious surfaces. Many important stormwater pollutants are airborne and buildup occurs on surfaces including roofs, roads and other paved areas. Duncan (2006) describes buildup as an equilibrium process, whereby dry weather deposition and removal tend to lead to a relatively constant quantity of pollutants present on impervious surfaces. Duncan (2006) concludes that buildup is not an important determinant of pollutant loads in runoff.

Washoff is a process where rainfall and runoff removes accumulated pollutants from impervious surfaces. It has been found that the washoff process is dependent on storm characteristics, catchment characteristics and the nature of the pollutants. While it has been common in the past to assume that most pollutants are washed off in the "first flush" of rainfall, many observations have not supported this theory. Duncan (2006) describes washoff as mainly dependent on rainfall energy. Low energy rainfall will not wash many pollutants off a surface; as rainfall intensity (and energy) increases, pollutant concentrations in runoff become slightly higher, and pollutant loads become significantly higher.

2.3.2 Urban area pollutant loads

A number of investigations within Darwin Harbour have identified that the water quality of the Harbour, particularly in the tributaries of the Harbour, has started to degrade as a result of wastewater and stormwater discharge. Although heavy metals, hydrocarbons and gross pollutants are considered important in the context of stomwater pollution, the major water stormwater quality parameters of concern to the harbour are total suspended solids (TSS), total phosphorus (TP) and total nitrogen (TN).

There have been some studies that quantified pollutant loads of TSS, TP and TN in runoff over the wet season. The Water Monitoring Branch (2005, p.25) estimated the following pollutant loads from urban areas:

- TSS: 590 kg/ha/year
- TP: 1.9 kg/ha/year
- TN: 9.4 kg/ha/year

Further, NRETA (undated) recommended adopting the following pollutant loads for urban areas:

- TSS: 590 $\pm$ 190 kg/ha/year
- TP: 1.9 $\pm$ 0.4 kg/ha/year
- TN: 9.4 $\pm$ 4.9 kg/ha/year

These pollutant loads are based on monitoring data collected in the Darwin Region. Detailed catchment monitoring has been undertaken at two urban sites (Karama Drain and Moil Drain) over two wet seasons at each site (1990-91 and 1991-92 at Karama, and 1995-96 and 1996-97 at Moil) (Kernohan and Townsend 2000, Padovan 2001). The monitoring involves measurement of streamflow and pollutant concentrations over time. These two data sets are combined for an estimate of pollutant loads. The monitoring data includes two seasons with above-average rainfall as well as two with below-average rainfall.

The load estimates above were compared to typical values estimated using the MUSIC modelling software. MUSIC includes pollutant parameters based on Duncan (1999). Duncan (1999) compiled data on pollutant concentrations in stormwater from a substantial body of information published in the literature worldwide. Mean values and typical ranges (± 1 standard deviation) are included in MUSIC, and the model generates a stochastic distribution of pollutant concentrations based on these mean values and ranges.

For a typical urban catchment in Darwin (50% impervious), the following pollutant loads were estimated using the MUSIC software:

- TSS: 1,650 kg/ha/year
- TP: 3.2 kg/ha/year
- TN: 30.0 kg/ha/year

These values are 2-3 times higher than those estimated on the basis of monitoring data. A possible explanation is that the streamflow monitoring has under-estimated flows.

Due to the discrepancy, a further source of data was consulted. In South-East Queensland, Brisbane City Council and the Gold Coast City Council have adopted MUSIC modelling parameters based on an extensive dataset gathered in Brisbane City Council's Stormwater Quality Monitoring Programme (Brisbane City Council 2003). The recommended parameters are summarised in the "Guidelines for pollutant export modelling in Brisbane" (Brisbane City Council 2003). These parameters were used in a second MUSIC model run for the same typical urban catchment, and the results are compared to those noted above. Results are summarised in Table 3 which shows a wide variation in pollutant load estimates from the three different sources. It is recommended that MUSIC parameters are used as default values for stormwater assessment at this stage until further interpretation of the local Darwin data occurs.

Table 3: Comparison of pollutant load estimates

Parameter	Estimated pollutant loads (kg/ha/year)		
	Water Monitoring Branch (2005)	**MUSIC default pollutant data (Duncan 1999)**	**Brisbane City Council (2003) pollutant data**
TSS	590	1,650	2,160
TP	1.9	3.2	4.3
TN	9.4	30.0	22.4

2.3.3 Seasonal patterns

It is thought that high pollutant loads are transported in runoff in the early part of the wet season, after a long period of pollutant build up on urban impervious surfaces during the dry season. However Kernohan and Townsend (2000) studied this issue in an urban catchment (Karama) over the 1991-92 wet season and found that:

- Between October – December (early part of the wet season), an average of 24% of total wet season contaminant loads were exported from the catchment.

- Most of the mass load of contaminants was exported from the catchment between January and March (mid wet season), corresponding with the period of highest rainfall.
- Concentrations of contaminants, particularly nitrogen and phosphorus, were marginally higher in storm flow in the early part of the wet season.
- When baseflow was taken into account as well as storm flow, the mass of most contaminants exported, relative to flow volume, was relatively constant throughout the wet season. The exception was nitrogen, where a relatively high proportion was transported in baseflow during the first three months of the wet season1.

Most contaminants are exported in wet season storm flow. Kernohan and Townsend (2000) found that in the Karama catchment over the 1991-92 wet season, most individual storms each exported a small proportion of total contaminants (less than 3%) while one or two particularly large storms exported more than 10% of total contaminant loads. They found that the most important determinant of pollutant export loads was storm volume, rather than contaminant concentrations.

2.4 Drainage design in the Darwin Region

2.4.1 Subdivision scale

Darwin and Palmerston Councils have both published Subdivision Development Guidelines (City of Palmerston, 2007 and Darwin City Council, 2005), which outline the requirements for stormwater drainage design. Both councils specify an initial and major design storm for different development zones, as shown in Table 4.

Table 4: Design storms for Darwin and Palmerston Councils

Local government area	Zones	Initial storm	Major storm
Palmerston City Council	Commercial	10 year ARI	100 year ARI
	All open space	2 year ARI	100 year ARI
	All other zonings	5 year ARI	100 year ARI
Darwin City Council	Zones B1, B2, B3, B4	10 year ARI	100 year ARI
	Industrial and R1 zones	2 year ARI	100 year ARI
	Open space and drainage reserves	1 year ARI	100 year ARI

Along roads, both councils have established requirements for maximum extents of inundation in the initial storm event, and both councils require the depth x velocity product to be 0.45 or less in the 100 year ARI event.

In open space and drainage reserves, both councils require flows to be contained within the boundaries and velocities to be 1.5 m/s or less in the 100 year ARI event. The City of Palmerston also requires flows to be contained within formal drains in the 2 year ARI event.

Both councils require floor levels to be set at least 300 mm above the major flood level.

[1] Kernohan and Townsend (2000) also found that for the subject catchment, 39% of the total wet season load of nitrogen was exported in baseflow. 11% of phosphorus and 2% of total suspended solids was exported in baseflow.

2.4.2 Allotment scale

In the Darwin Region, houses and other buildings may be constructed with or without downpipes. Where houses don't have downpipes, allotment drainage may be managed in a gravel trench. In the City of Palmerston, residential lots larger than 600 m^2 do not need an underground drainage system, and excess runoff can discharge to the street as sheet flow. Smaller allotments and all commercial and industrial allotments need to have a formal drainage system connected to the underground street drainage system.

Due to high groundwater levels in the wet season, subsoil drainage is generally required to protect structures from high groundwater levels. Subsoil drainage is also usually required in road reserves to protect road infrastructure from groundwater impacts.

Neither Darwin nor Palmerston Council requires on-site detention for low flows or flood protection.

3 Ecology of natural ecosystems in the wet-dry tropics and Darwin region

A review of Australia's tropical aquatic ecosystems, such as floodplains, wetlands and lagoons provides valuable insights into the potential ecology of constructed vegetated systems for stormwater treatment. Natural systems provide important guidance on the design of constructed systems, particularly in relation to:

- Hydrological regime of wetlands
- Vegetation types
- Vegetation succession and adaptation
- Communities
- Soil and groundwater interactions

This section provides a summary review of the research that has been conducted in the floodplain aquatic ecosystems in the wet-dry tropics of Northern Territory and aquatic ecosystems around Darwin. This review focuses on the ecology and characteristics of natural systems that are relevant to stormwater treatment in the Darwin Region.

3.1 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 3. 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 4 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.

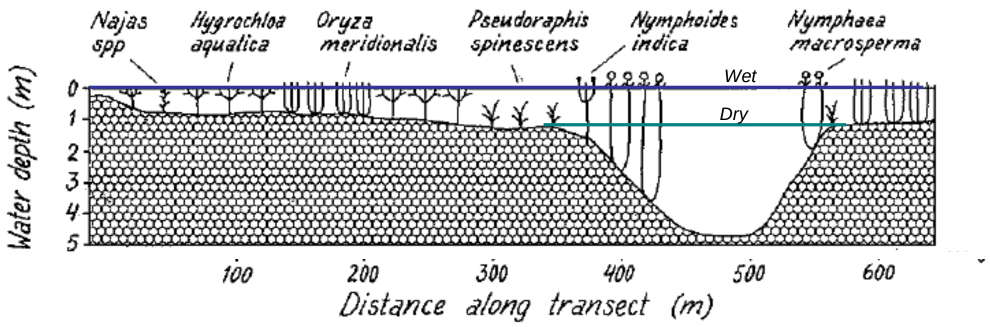


Figure 3: Idealised Cross Section through Aquatic Ecosystem (modified from Cowie, 1999)

Figure 4: Image of East Alligator River Floodplain during the wet showing an open water zone in foreground to fringe melaleuca zone in background

3.2 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 5 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.

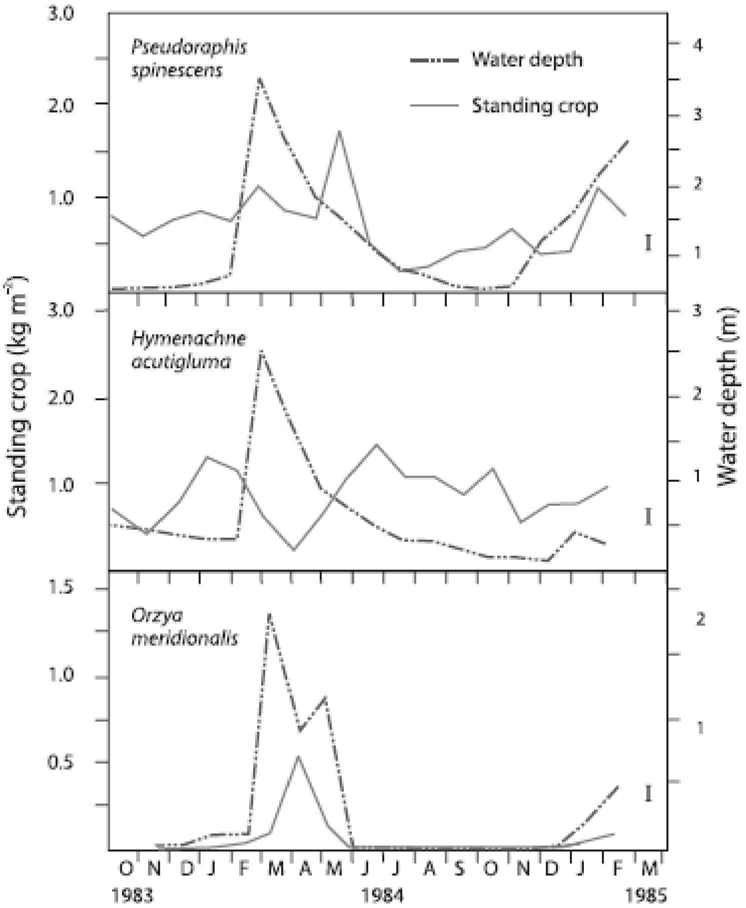


Figure 5 Biomass during the wet season and dry season (Finlayson et al, 2006)

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.

3.2.1 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 deep, and more than 50m wide and can completely cover lagoons. Studies of Finiss River near 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*.

3.2.2 Wetland Depth and Inundation Duration and Timing

Vegetation is strongly influenced by timing, duration and intensity of the wet season. Small differences in 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 6. 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).

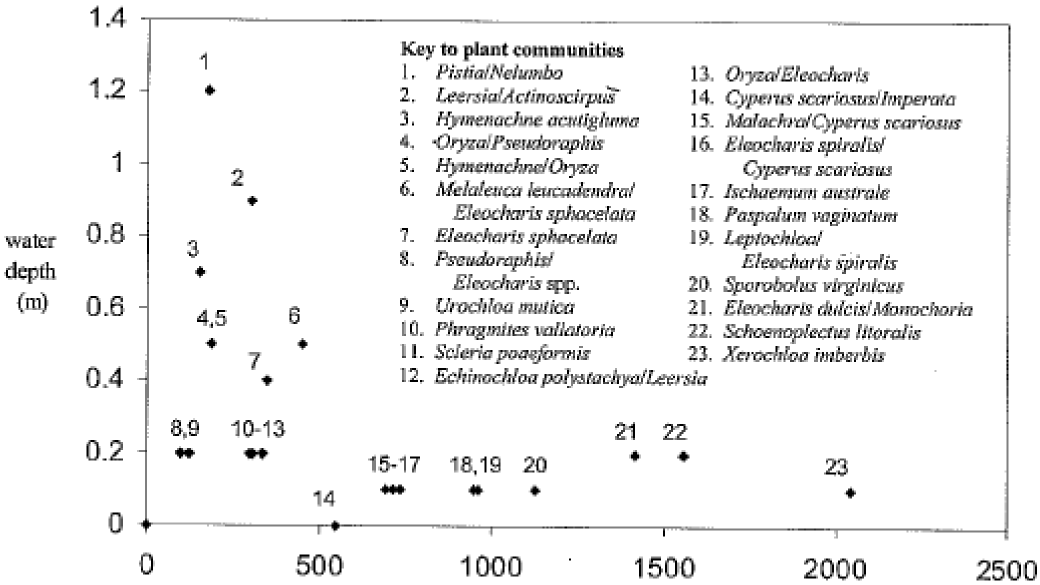


Figure 6 Salinity and flow depth relationship

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.

3.3 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 7. 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 7 *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 8. 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).

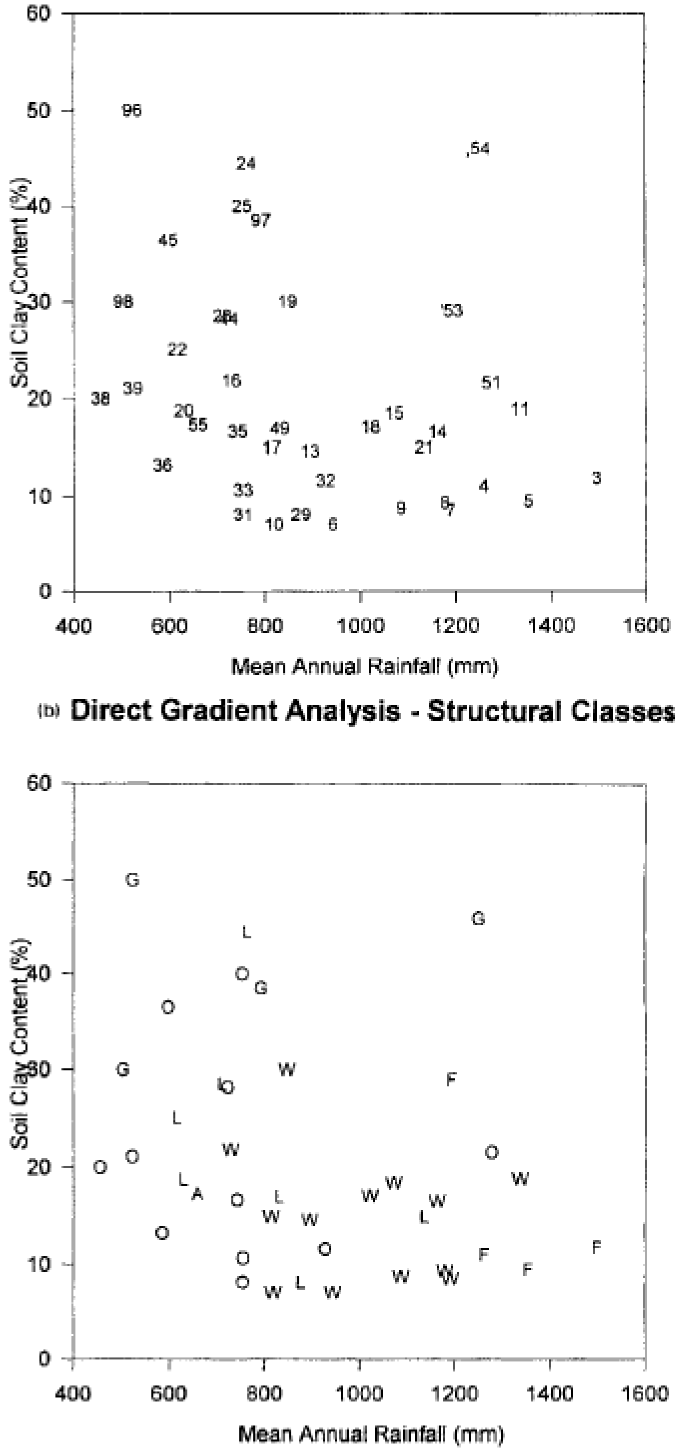


Figure 8 Community types based on rainfall and soil clay content (F= forest; W = woodland O=open woodland, L=low open woodland A=Lancewood-woodland G= grassland) (Williams, 1996)

3.4 Weeds

The alien species that are likely to colonise stormwater treatment systems are also likely to be those species that are widespread tropical weeds in the NT. Most weed species are associated with human activities and occur in disturbed ground areas:

- *Salvinia molesta* is an invasive free floating aquatic fern which grows rapidly and forms dense floating mats. Salvinia is common in many river systems and floodplains of the Northern Territory as well as in many parts of Australia. *Salvinia* forms dense mats and can cover waterbodies, reducing oxygen levels and shading out native submerged species. The dense mats also make manual removal or chemical control difficult. *Salvinia* grows best in still or slow moving water; tolerates a wide range of temperatures and salinties and thrives in nutrient rich water. Thus it is able colonise most water bodies.

- *Mimosa pigra* is a prickly shrub which is a native of South America. It is a tall shrub which shades out most natives. It is an invasive weed which flourishes in deeply flooded seasonal areas. The seed is largely water dispersed and populations can double within a year and a half.

- *Urochloa/Brachiara mutica* (para grass) is a perennial grass up to about 1m tall, which is native of Africa. It is commonly used as an improved pasture grass on floodplains in the NT. Para grass is capable of invading and dominating wetlands occupied by natives such as *Eleocharis*, *Oryza* and *Hymenachne* spp. Para grass rarely occurs in water deeper than 0.6m. Para grass reproduces vegetatively through stolons.

- *Eichhornia crassipes* (Water Hyacinth) is a floating weed with a fibrous root system which can form dense floating mats. *Eichhornia crassipes* depletes water bodies of oxygen by preventing air transfers at the surface. It can reproduce by seed or vegetative reproduction.

Other potential weed species which are common in riparian zones are *Cabomba Caroliniana*, Mission Grass (*Pennisetum polystachion*) and Gamba Grass (*Andropogon gayanus*), the annuals *Hyptis suaveolens*, *Sida acuta*, *Sida cordifolia*, *Alysicarpus vaginalis* and *Euphorbia hirta* and the perennial vine *Passiflora foetida*.

Most weedy plant infestations occur in anthropogenic habitats such as settlements and roadways (Cowie and Werner 1993). Severe infestations of alien plant species have been reported in natural habitats such as riparian zones, especially in those areas disturbed by animals such as Buffalo or pigs (Gardner et al 2002). Some weeds can invade intact native communities (i.e. Salvinia, Mimosa, Brachiaria) (Gardner et al 2002), yet most weedy species establish in areas that have been disturbed.

There are potential mechanisms to reduce weed establishment and control or exclude the growth of weeds. The growth of weeds can be controlled by:

a) Reducing resources available to the plant; i.e. reducing light, water, or nutrients. Densely vegetating stormwater treatment devices shades weed propagules, and provides competition for resources such as space and nutrients which are required by weed species for successful growth.

b) Destroying weeds where they occur. Certain species may be killed by chemical sprays, mechanical removal, flooding or draining of the wetland, and fire. However, unless the area previously occupied by the weeds is populated by other species, the disturbed area is likely to be re-colonised by weeds.

c) Minimising the extent of permanent water (i.e. creating only small permanent water zones surrounded by ephemeral zones which dry between events).

Long-term weed management should consider dense planting of design species to exclude weeds. This will also have the effect of reducing nutrients available to weed propagules and will shade young weed plants, making it more difficult for weeds to establish. Floating species such as Salvinia may require physical controls such as chemical sprays, mechanical removal, and the introduction of biological controls such as the Salvinia weevil.

3.5 Geology and soils

The bedrock geology in the Darwin Region consists of dolomite, carbonate rocks, sandstone, shale, siltstone, schist, granite and metamorphic rocks. Above the bedrock, there is generally a 20-50 m layer of sandstone, siltstone and claystone, then above that, most of the region is capped with a 5-10 m layer of lateritic soils (Haig and Townsend, 2003).

Haig and Townsend (2003) describe several different regions around Darwin, classified by their geomorphology:

- Around the coastline, there are extensive intertidal flats consisting of sand and shell depositions along the shoreline, and mud, clay and silt below the high tide. Mangroves occur where drainage channels deposit clay and silt.
- Within three metres of the high tide level, there are flat, poorly drained floodplains, swamps and marshes. These areas are seasonally flooded and high loads of silt and clay are deposited.
- At slightly higher levels, there are ephemeral and perennial lagoons and broad drainage channels, which receive spring flows. Soils are sand, silt and clay deposited during flow events.
- Inland, there are plains and dissected plateaux. The plains consist of sandy to loamy soils overlain by laterite sediments. The dissected plateaux are hilly and have poorer soils on boulder-strewn slopes.
- There are also some areas of granitic soils in the upper catchment of Darwin River.

The soils of aquatic ecosystems, especially those associated with floodplain zones are the result of deposition of fine clay particles during the wet season floods. These soils in contrast to the heavily leached sandstones and siltstones and laterite areas of the escarpments and woodlands, are fertile and fine textured.

The most extensive soils on the floodplain are 0.5m to 1m clays overlying estuarine muds. These soils are typically 'cracking clays' which seal again during the late dry season – early wet season allowing water to pond.

3.6 Groundwater

Groundwater characteristics of the Darwin Region have been described by Haig and Townsend (2003) and the following summary is derived from their paper.

The dolomite and carbonate rocks contain significant bedrock aquifers, while fractured sandstone and siltstone bedrock also contains some groundwater. In some areas the dolomite aquifer is semi-confined and discharges via surface springs, for example at Howard Springs. Groundwater extraction potential around the region is largely dependent on the underlying bedrock geology.

The shallow sandstone, siltstone and claystone sediments form a regional unconfined aquifer system. This aquifer is recharged during wet season via direct infiltration. Groundwater levels rise during the wet season, then gradually reduce through the dry season, as groundwater moves into the deeper bedrock aquifers or contributes to stream baseflow. Typically groundwater tables fluctuate by approximately 8-10 m seasonally during the year.

3.6.1 Recharge

The soil moisture deficit needs to be met before groundwater recharge begins to occur. Typically 150-165 mm of rainfall is required to satisfy the soil moisture deficit, before rainfall begins to contribute to streamflow or groundwater recharge. Recharge generally begins around January, around two months into the wet season.

3.6.2 Drainage

Shallow groundwater drainage occurs throughout the dry season, starting in the higher parts of the catchment and progressing down to lower lying areas. At the end of the dry season, there are only a few low-lying areas which retain wetlands after most of the shallow groundwater has drained away. These "perched lagoons" are able to persist through the dry season due to a layer of organic mud that is relatively impermeable. Evaporation reduces the water levels in these lagoons, but the deeper of them retain a permanent pool for the entire dry season.

3.6.3 Impacts of urban development

It has been found that urban development results in increased drawdown of groundwater levels during the dry season (Haig and Townsend, 2003). This is due to additional groundwater extraction via groundwater bores. Monitoring of groundwater bores at a number of rural and urban locations in the Darwin region has found that recharge is still effective during the wet season, and there was no reduction in average wet season groundwater levels (i.e. the aquifers are completely recharged during the wet season).

4 Swales

4.1 Conventional stormwater swales

Vegetated swales are used to convey stormwater in lieu of, or with, underground pipe drainage systems, and to provide removal of coarse and medium sediments. They are commonly combined with buffer strips and bioretention systems, or may be used as a pre-treatment measure upstream of a wetland. Swales utilise overland flow and mild slopes to convey water slowly downstream. They provide a means of disconnecting impervious areas from downstream waterways, assisting in protecting waterways from damage by frequent storm events, by reducing flow velocity compared with piped systems.

The interaction between stormwater flow and vegetation within swale systems facilitates pollutant settlement and retention. Even swales with relatively low vegetation height (such as mown grass) can achieve significant sediment deposition rates provided flows are well distributed across the full width of the swale and the longitudinal grade of the swale is kept reasonably low (typically less than 4 % grade) to maintain slower flow conditions. Darwin and Palmerston Councils both require velocities to be 1.5 m/s or less in the 100 year ARI event.

Swales alone cannot provide sufficient treatment to meet current best practice stormwater treatment/water quality objectives, but can provide an important pretreatment function for other WSUD measures in a treatment train, enabling water quality objectives to be met. Swales are particularly good at coarse sediment removal as a pretreatment for wetlands and bioretention systems. A typical cross-section of a swale is shown in Figure 9. Figure 10 shows some examples of swales and bioretention swales from around Australia. The main drains in Palmerston are grass-lined drains with 750 mm low flow pipes.

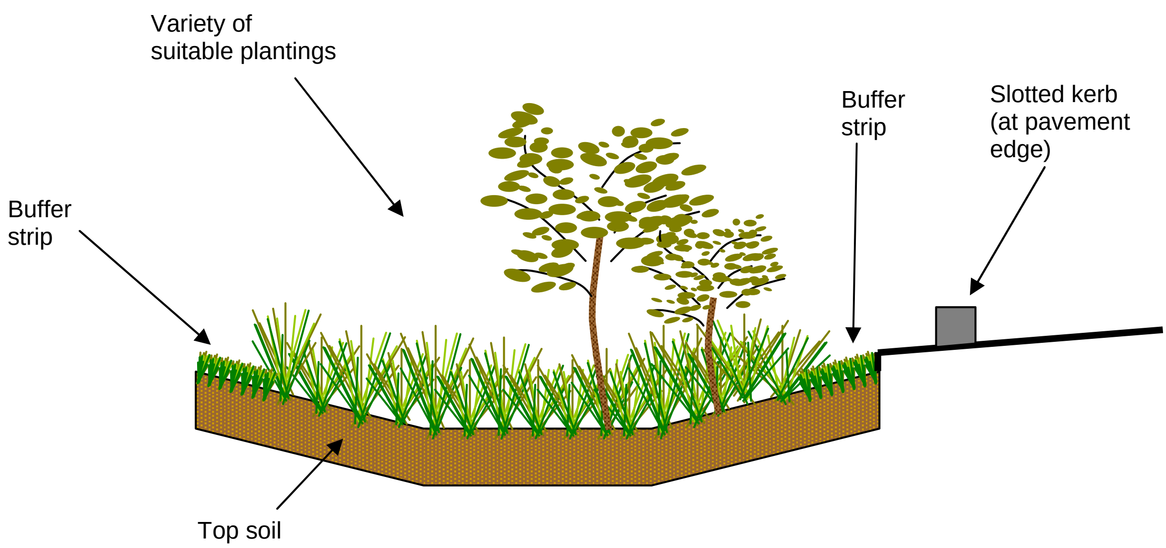


Figure 9: Typical swale cross-section

Kinfaun Estate, Hastings, Victoria

Lynbrook Estate, Melbourne

Coomera Waters, Gold Coast

Lyons, Darwin

Baltrusol Estate, Victoria

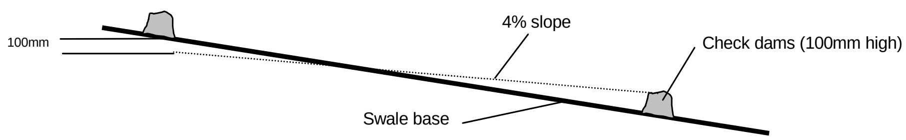
Coomera Waters, Gold Coast

Figure 10 Selected swales and bioretention swales

Buffer strips (or buffers) are areas of vegetation through which runoff passes while travelling to a discharge point. They reduce sediment loads by passing a shallow depth of flow through vegetation and rely upon well distributed sheet flow. Vegetation tends to slow velocities and coarse sediments are retained. With their requirement for uniformly distributed flow, buffer strips are suited to treatment of road runoff in situations where road runoff is discharged via flush kerbs or through regular kerb 'cut-outs'. In these situations, buffer strips can form part of a roadside swale system, that is, the swale batter that receives the distributed inflows from the adjoining road pavement (as shown in Figure 9).

Design considerations for swales are outlined in Table 5.

Table 5: Design considerations for swales

Design issue	Key considerations
Landscape design	Swales may be located within parkland areas, easements, carparks or along roadway corridors within footpaths or centre medians. Landscape design of swales and buffer strips along the road edge can assist in defining the boundary of the road or street corridors as well as enhancing landscape character. It is important that the landscape design of swales and buffers addresses stormwater quality objectives whilst also incorporating landscape functions.
Hydraulic design	For water quality improvement, swales need only focus on ensuring frequent storm flows (typically up to the 3 month ARI (Average Recurrence Interval) flow) are conveyed within the swale profile. In most cases, however, a swale will also be required to provide a flow conveyance function as part of a minor drainage and/or major drainage system. In particular, swales located within road reserves must also allow for safe use of adjoining roadway, footpaths and bike paths by providing sufficient conveyance capacity to satisfy engineering infrastructure design requirements. In some cases, flows will encroach onto the road surface to acceptable levels. It may also be necessary to augment the capacity of the swale with underground pipe drainage to satisfy the road drainage criteria. This can be achieved by locating overflow pits (field inlet pits) along the invert of the swale that discharge into an underlying pipe drainage system. Careful attention should be given to the design of overflow pits to ensure issues of public safety (particularly when raised grates are being used) and aesthetic amenity are taken into account. The longitudinal slope of a swale is another important hydraulic design consideration. Swales generally operate best with longitudinal slopes of between 1 % and 4 %. Slopes milder than this can become waterlogged and have stagnant ponding, however, the use of subsoil drains beneath the invert of the swale can alleviate this problem by providing a pathway for drainage of any small depressions that may form along the swale. For longitudinal slopes steeper than 4 %, drop structures (also called "check dams" – low level rock weirs of approximately 100 mm height) across the base of the swale, or equivalent measures, can help to distribute flows evenly across the swales, as well as reduce velocities and potential for scour. It is also important to protect the vegetation immediately downstream of drop structures. Rock pitching can be used to avoid erosion. A rule of thumb for locating drop structures is for the crest of a downstream drop structure to be at 4 % grade from 100 mm below the toe of an upstream drop structure. The impact of drop structures on the hydraulic capacity of the swale must be assessed as part of the design process.  It is important to ensure velocities within swales are kept low (preferably less than

Design issue	Key considerations
	0.5 m/s for minor flood flows and not more than 2.0 m/s for major flood flows) to avoid scouring of collected pollutants and vegetation. When located within road reserves, swales can be subjected to velocities associated with major flood flows (100 year ARI) being conveyed along the road corridor. Therefore, appropriate checks need to be undertaken on the resultant velocities within the swale to ensure the maximum velocity within the swale does not exceed 2.0 m/s. Similar checks should also be undertaken to assess depth x velocity within the swale, at crossings and adjacent to pedestrian and bicycle pathways to ensure public safety criteria are satisfied.
Vegetation types	Swales can use a variety of vegetation types including turf, sedges and tufted grasses. Vegetation is required to cover the whole width of the swale, be capable of withstanding design flows and be of sufficient density to prevent preferred flow paths and scour of deposited sediments. Grassed swales are commonly used in residential areas and can appear as a typical road footpath. Grass swales should be mown and well maintained in order for the swale to operate effectively over the long term. Denser vegetated swales can offer improved sediment retention by slowing flows more and providing vegetation enhanced sedimentation for deeper flows. However, densely vegetated swales have higher hydraulic roughness and therefore require a larger area and/ or more frequent use of swale field inlet pits to convey flows compared to grass swales. Densely vegetated swales can become features of the urban landscape and once established, require minimal maintenance and are hardy enough to withstand large flows.
Swale crossings	A key consideration when designing swales along roadways is the requirement for provision of driveway crossings (or crossovers). Driveway crossings can be 'at-grade' or 'elevated'. 'At-grade' crossings follow the profile of the swale (e.g. like a ford), while 'elevated' crossings are raised above the invert of the swale (e.g. like a bridge deck or culvert). Crossings constructed 'at-grade' reduce the maximum allowable swale batter slopes to approximately 1 in 9 to ensure vehicles can traverse the crossing without bottoming out. This means the swale will have a shallow profile thus reducing its flow conveyance capacity. 'At-grade' crossings are typically cheaper to construct than elevated crossings, however they need to be constructed at the same time as the swale to avoid damaging the swale. This imposes a fixed driveway location on each allotment, which can potentially constrain future house layouts. 'At-grade' crossings are best suited to developments where the spacing between crossings is typically more than 15 m.   'Elevated' crossings are not appropriate in all street applications; however, where appropriate, they can be designed as streetscape features. They also provide an opportunity for locating drop structures (to distribute flows) or to provide temporary ponding above a bioretention system. A major limitation with 'elevated' crossings can be their high life cycle costs compared to 'at-grade' crossings (particularly in dense urban developments) due to the need for on-going maintenance. Safety concerns with traffic movement adjacent to 'elevated' crossings, concentration of

Design issue	Key considerations
	flows and the need for downstream scour protection, and the potential for blockages of small culvert systems beneath the crossing are other possible limitations. These limitations can be overcome by careful design through the use of spanning crossings rather than using small culverts and through the use of durable decking materials.
Traffic controls	Another design consideration is keeping traffic and building materials off swales (particularly during the building phase of a development). If swales are used for parking then the topsoil will be compacted and the swale vegetation may be damaged beyond its ability to regenerate naturally. In addition, vehicles driving on swales can cause ruts along the swale that can create preferential flow paths that will diminish the swale's water quality treatment performance as well as creating depressions that can retain water and potentially become mosquito breeding sites. Traffic control measures can include: • Planting the swale with dense vegetation • Providing a physical barrier such as a kerb (with breaks to allow distributed water entry to the swale) or bollards and/ or street tree planting. Physical barriers are recommended at corners, intersections, cul-de-sac heads and at traffic calming devices.
Services	Within road reserves, service corridors are commonly required. If swales are constructed in the service corridor, care should be taken to ensure the service conduits do not compromise the performance of the swale. Consideration will also need to be given to access to services for ongoing maintenance without the need to regularly disrupt or replace the swale. Sewers located beneath swales are to be fully welded polyethylene pipes with rodding points.

4.2 Design considerations in the wet/dry tropics

4.2.1 Vegetation

Swales in the wet/dry tropics can be designed to function in the same hydraulic manner as in temperate zones. The major issue with the design of the swale is the selection and maintenance of vegetation within the swale. The large and consistent rainfall will be conveyed by the swale during the wet months while during the dry months the absence of rainfall means the swale dries out for up to 8 months of the year. Maintaining a cover of vegetation is considered important for both amenity reasons and to to prevent preferred flow paths and scour. In this context, two key points are provided in relation to selection of vegetation for swales:

- While grassed swales are commonly used in residential areas turf will not be able to withstand long dry periods unless the swale is appropriate irrigated.

- Denser vegetated swales with native grasses, sedges, shrubs and trees could be used. Dryland grass species adapted to the wet dry tropics would be suitable. However native grasses tend to be sparse with low vegetation cover during the dry. The two key issues associated with this are

  - The aesthetics of such a swale as a component of the urban design

  - The ability of the vegetation to provide sufficient cover and treatment during the beginning of the wet after the first storms of the season.

4.2.2 Hydraulic design

The hydraulic design of a swale is similar to the design for temperate areas. For water quality treatment the principle design is for the majority of flows to be passed along the swale. This design criteria is typically for up to 90% of the volume of urban stormwater to be conveyed by the swale. In the Darwin region this will be achieved by diverting flows in the vicinity of half the one in one year ARI.

If swales are designed to also convey the standard design, typically between the 1 in 2 and 1 in 10 year ARI as outlined in section 2.4.1, then the size of the swale system can be potentially significant. For example the size of a swale to convey the 1in 5 year ARI for a 30 hectare residential catchment with an average slope of 1 to 2% would require a swale with a typical width of 20m and a typical depth of 0.5m. This corridor has a potentially significant land take, which may not be possible in all development scenarios. It may be necessary to provide a combination of swale with pit and pipe.

Appropriate design of swales is required to ensure that plants can establish on the surface of the swale and that the swale is not scoured out causing gully erosions. Designs measures adopted for temperate regions are also appropriate for the Darwin region and include

- Drop structures where slopes and velocities are high
- Reducing velocities by appropriate swale configurations (the depth x velocity product as outlined in section 2.4.1 should be maintained for swales in the Darwin region.)
- Scour protection at key points such as stormwater inlets

4.3 Potential swale solutions

The key design issue for swales is the selection and management of appropriate vegetation. Through careful selection of plants it may be possible to create functioning swales with few adaptations from temperate regions of Australia. This is also particularly relevant considering that there are often low flows from irrigation runoff during the dry season which could be used to provide some available soil moisture for plants.

There are also management schemes available as well. One potential solution to providing suitable grass and native vegetation swales is to irrigate swales during the dry season.

The irrigation of grass swales during the dry season will ensure that the grass survives through the dry season. Turf systems are typically shallow rooted and without irrigation will not survive the dry season. The use of hardy turf species such as *Zoysia* and *Paspalum* species will also reduce water usage.

Irrigation of native species can be provided by two distinct methods:

- Throughout the dry season to create a different aesthetic. Many native plants during the dry seasons survive in a xerophytic form, whereby plants senesce and or go to seed. If an 'evergreen' aesthetic is desired it is possible to plant native grasses and sedges which do not senesce but will require irrigation throughout the dry season.
- At the beginning of the wet season to ensure that plants have established before the first storms of the wet season. Early irrigation to establish the plants will ensure that new shoots and seedlings are established.

Irrigation systems impose a high maintenance burden on councils and communities to maintain the swale. It may be appropriate on main arterial roads, where current maintenance practices sometimes include irrigation undertaken by the Department of Planning and Infrastructure. However it is unlikely to be appropriate along smaller roads where the maintenance is the responsibility of Darwin City Council and the City of Palmerston.

5 Wetlands

5.1 Conventional stormwater wetlands

Wetlands are a common treatment measure used to treat stormwater runoff in temperate climates. Constructed wetland systems are shallow, extensively vegetated water bodies that use enhanced sedimentation, fine filtration and biological uptake processes to remove pollutants from stormwater. Water levels rise during rainfall events and outlets are configured to slowly release flows, typically over two to three days, back to dry weather water levels. In addition to treating stormwater, constructed wetlands can also provide habitat, passive recreation, improved landscape amenity and temporary storage of treated water for reuse schemes.

Wetlands generally consist of an inlet zone (sedimentation basin to remove coarse sediments), a macrophyte zone (a shallow heavily vegetated area to remove fine particulates and uptake soluble pollutants) and a high flow bypass channel (to protect the macrophyte zone from scour and vegetation damage). Figure 11 shows the key elements of constructed wetland systems. Figure 12 shows some examples of constructed wetlands from around Australia.

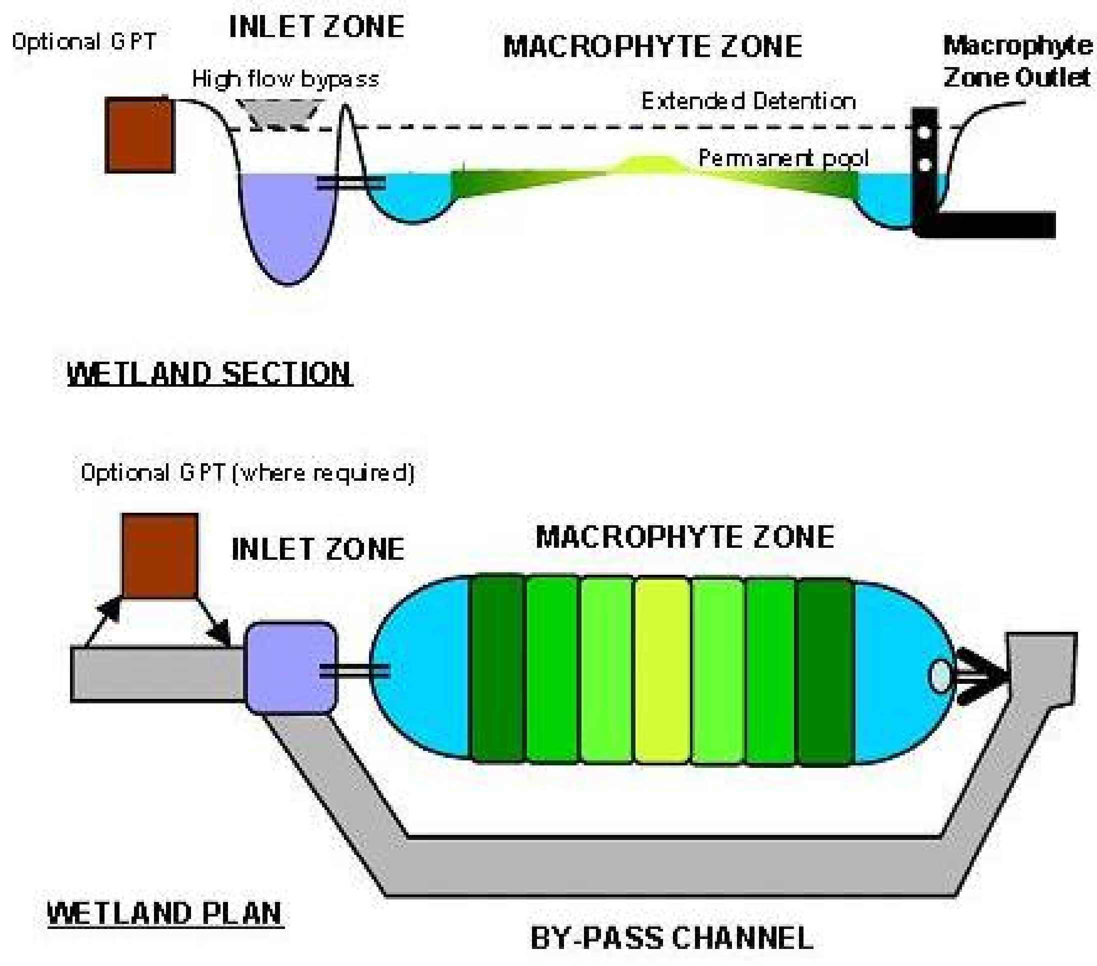


Figure 11: Schematic section and plan of a constructed wetland

Victoria Park, Sydney

Victoria Park, Sydney

Coomera Waters, Gold Coast

Coomera Waters, Gold Coast

Royal Park, Melbourne

Figure 12: Examples of constructed wetlands

The operation of constructed wetlands involves the interaction between stormwater runoff, vegetation and hydraulic structures and the successful implementation of constructed wetlands requires appropriate integration into the landscape design. In this regard, Table 6 provides an overview of the key design issues that must be considered when conceptualising and designing constructed wetlands.

Table 6: Design considerations for constructed wetlands

Design issue	Key considerations
Landscape design	Constructed wetlands are often located within accessible open space areas and can become interesting community features. Landscape design aims to ensure that marsh planting fulfils the intended stormwater treatment function as well as integrating with their surrounds. Opportunities to enhance public amenity and safety with viewing areas, pathway links, picnic nodes and other elements should be exploited. Community education through signage and public art can also be explored. It is important that the landscape of constructed wetlands addresses stormwater quality objectives whilst being sensitive to these other important landscape aims.
Detention time and hydrologic effectiveness	Hydrologic effectiveness is a measure of the mean annual volume of stormwater runoff captured and treated within the wetland and is expressed as a percentage of the mean annual runoff volume generated from the contributing catchment (it should be greater than 80 % for well designed wetlands). Detention time is the time taken for each 'parcel' of water entering the wetland to travel through the macrophyte zone assuming 'plug' flow conditions. Detention time influence's a wetland's pollutant removal efficiency and it is recommended that the notional detention time should be approximately 72 hours to remove nutrients effectively from urban stormwater.
Hydrodynamic design	Poor wetland hydrodynamics is often identified as a major contributor to wetland operational and management problems. The general wetland layout, selection of plant species and design of inlet, outlet and bypass structures all influence a wetland's hydrodynamics. Good hydrodynamic design will encourage: • Uniform distribution of flow velocity, to avoid stagnant areas or short circuit flowpaths • Wetlands sized appropriately for their catchments and with suitable depths to ensure regular flows through the system and a wetting and drying pattern that suits each vegetation zone • Uniform vertical velocity profile, to avoid stratification • Protection from scouring during periods of high flows
Inlet zone and high flow bypass	The inlet zone of a constructed stormwater wetland is designed as a sedimentation basin. Its primary role is to remove coarse to medium sized sediment (i.e. 125 µm or larger) prior to flows entering the macrophyte zone. This ensures the vegetation in the macrophyte zone is not smothered by coarse sediment. Large wetlands also usually require a gross pollutant trap as part of the inlet zone, to target litter and debris. The second role of the inlet zone is the control and regulation of flows entering the macrophyte zone. The outlet structures from the inlet zone are designed such that flows up to the 'design flow' (typically the 1 year ARI) enter the macrophyte zone whereas 'above design flows' are bypassed around the macrophyte zone. This protects the macrophyte zone vegetation against scour during high flows. Note that when space is constrained, the size of the inlet zone should not be

Design issue	Key considerations
	reduced – the macrophyte zone area should be reduced if necessary.
Macrophyte zone	The layout of the macrophyte zone needs to be configured such that system hydraulic efficiency is optimised and healthy vegetation sustained. Design considerations include: • The preferred extended detention depth is 0.5 m. Deeper extended detention depths up to a maximum of 0.75m may be acceptable • The bathymetry of the macrophyte zone should be designed to promote a sequence of ephemeral, shallow marsh, marsh and deep marsh zones in addition to small open water zones • The macrophyte zone is required to retain water permanently and therefore the base must be of suitable material to retain water (e.g. clay or synthetic liner) • The bathymetry of the macrophyte zone should be designed so that all marsh zones are connected to a deeper open water zone to allow mosquito predators to seek refuge in the deeper open water zones during periods of extended dry weather • Particular attention should be given to the placement of the inlet and outlet structures, the length to width ratio of the macrophyte zone and flow control features to promote a high hydraulic efficiency within the macrophyte zone • Provision to drain the macrophyte zone for water level management during the plant establishment phase should also be considered • The macrophyte zone outlet structure needs to be designed to provide a notional detention time (usually 72 hours) for a wide range of flow depths. The outlet structure should also include measures to exclude debris to prevent clogging

Other specific design considerations are covered in detailed technical guidelines, including:

- Wetlands integrated into retarding basins
- Design to avoid mosquito breeding
- Plant selection
- Design for maintenance access
- Design for public safety and amenity

5.2 Design considerations in the wet/dry tropics

In the context of the wet/dry tropics, constructed wetlands will not fill and drain regularly like wetlands in temperate zones. The large and consistent rainfall during the wet months will ensure that wetlands remain charged during the wet. During the dry months the absence of rainfall will result in wetlands drying out, due to high evaporative losses and no top up from stormwater runoff.

Natural freshwater lagoons in the Darwin Harbour region provide an insight into the way in which stormwater wetlands may function in the region. A recent inventory of freshwater lagoons in the

Darwin region was completed by NRETA (Schult, 2004). This and other research has illuminated the key features of the freshwater lagoons:

- Most of the lagoons are less than 3 m deep (Schult and Welch, 2006)
- Vegetation in the lagoons ranges from, for example, a continuous cover of paperbarks, to submerged macrophytes
- The lagoons are underlain by relatively impermeable organic material and clay, which is thought to retain water above the groundwater levels in the dry season
- Some of the lagoons dry out seasonally, while others retain permanent water
- Out of fifteen lagoons monitored for one year, water level fluctuations between the wet and dry seasons varied from around 1.5 to 3.0 m, with an average of 2.0 m (Schult and Welch, 2006)
- Seasonal changes in water levels are accompanied by significant changes in water quality and vegetation cover
- Pollutant concentrations in lagoons tend to reach a peak at the end of the dry season, with nutrient and chlorophyll-a concentrations increasing as lagoons dry out (Lloyd, 1999). Dissolved solute concentrations also increase due to evaporation during the dry season and re-suspension of sediments when water levels are very low (Schult and Welch, 2006).

Figure 13 shows seasonal water level and vegetation changes in a freshwater lagoon.

Figure 13: Seasonal changes in water level and vegetation in Korebum Lagoon – May, August, November and February (Schult and Welch, 2006)

5.2.1 Wetland sizing

Due to the high wet season rainfall, it is expected that stormwater treatment wetlands in the Darwin Region will be larger than those in southern Australia, to achieve the same treatment performance.

The draft *Water Sensitive Urban Design Objectives for Darwin - Discussion Paper* (Ecological Engineering, October 2007) included some indicative sizing curves for conventional stormwater treatment wetlands in the Darwin Region. These showed that wetlands may need to be around 6% of an urban catchment area to achieve best practice treatment targets. However the sizing curves only give a very rough indication of treatment performance, as wetlands for the Darwin Region will be designed differently to conventional stormwater treatment wetlands. This is discussed in Section 5.3 below. Wetland sizing will need to be revisited as the conceptual wetland designs are refined.

5.2.2 Hydraulic design

Wet season stormwater flows are relatively high, as rainfall tends to occur in short, high intensity storms. Wetlands in the Darwin Region will need to be designed for these conditions. Hydraulic design considerations apply in particular to the inlet pond, high flow bypass and low flow outlet:

- An inlet pond needs to be designed for the high wet season rainfall.
- A diversion structure needs to be designed to allow low flows into the wetland for treatment, and safely bypass high flows to protect the wetland itself from scour and erosion. Ideally a high proportion of the flow volume should be treated (hydrologic effectiveness should be greater than 80%).
- Normally in southern Australia, wetlands are designed for a nominal 72-hour detention time, which is regulated via a riser outlet. The extended detention fills after a storm event, and then is gradually drawn down over 72 hours. This design would need to be modified for the wet-dry tropics, where storm events are more frequent through the wet season. These wetlands may operate with a relatively constant water level through the wet season and a suitable detention time could still be achieved by ensuring plug flow occurs, and sizing the wetland to contain a nominal three days' rainfall volume.

5.2.3 Plant selection

Wetland plants that occur naturally in the freshwater lagoons, floodplains and wetlands of the Darwin Region are likely to be appropriate for stormwater treatment wetlands. These local plants are able to tolerate the high water level fluctuations and long periods of wetting and drying. Plant communities such as *Eleocharis* sedgelands, *Oryza*, *Pseudoraphis* and *Hymenachne* grasslands, *Melalueca* forests and floating mats are likely to be key components of the design. More detail on these communities is discussed in section 3.

Vegetation die-off during the dry season is common for many species of aquatic vegetation in the Darwin region. Wetland design needs to manage the transition from wet season to dry season and vice versa to ensure that this does not compromise treatment performance or aesthetics of the wetland. Details of individual plant species and wetland design are given in section 5.3.

Constructed wetlands are typically designed with a number of different zones which reflect water depth and length of inundation. Constructed wetlands in the Darwin region will mimic natural system vegetation zones. The design of these zones, and the selection of vegetation, in the constructed wetland will be strongly influenced by the corresponding zones in natural systems as outlined in section 3.2.

5.2.4 Weeds

Similar to the natural freshwater lagoons, weed management will be an important issue in constructed wetlands.

Several vigorously growing and ecological in highly competitive weeds occur in wetland areas of the Northern Territory. Stormwater treatment systems should be designed to prevent or discourage the establishment of these species (Cowie, 2003):

- *Mimosa pigra*

- *Salvinia molesta*
- *Brachiaria mutica* (Paragrass)
- *Hymenachne amplexicaulis*
- *Cabomba caroliniana*
- *Echinochloa polystachya*

Mission Grass and Gamba Grass should also be discouraged.

More detail on weeds and management of weeds can be found in Section 3.4.

5.2.5 Algae

Research undertaken by Ganf (2007) found that the availability of nutrients currently limits net biomass accumulation in NT rivers, and hence rivers and waterbodies are susceptible to algal blooms under nutrient enrichment.

Key factors leading to blooms are:

- The supply of nutrients, phosphorous and nitrogen in particular
- The depth of the surface mixed layer
- Turbidity and the availability of sunlight
- The rate of discharge of waterbodies

Wetlands provide a high risk environment, especially at the end of the wet season, as nutrient levels increase, discharge through the wetland is minimal, and sunlight and temperatures are high.

Research by Ganf (2007) has shown that in the Darwin region brown algae groups dominate the phytoplankton communities during the wet season, with the dominance of brown algae diminishing during the early dry as the contribution of the blue green algae and green algae communities increased significantly. This is shown in Figure 14 below. Bioassay studies showed that with the addition of N and P produced high concentrations of total chlorophyll.

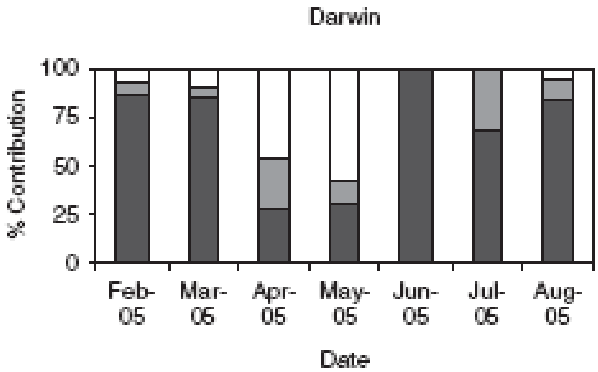


Figure 14 Seasonal variation in algal groups brown (dark grey), blue-green (light grey) and green (white)

Monitoring at fifteen lagoons in Darwin showed that nutrients and chlorophyll increased over the dry season (Schult and Welch, 2004):

- Dissolved phosphorous from 0.001 to 0.005 mg/L
- TP from 0.008 to 0.045 mg/L

- TKN from 0.32 to 2.2 mg/L
- Nitrate from <0.004 to 0.54 mg/L
- Chlorophyll a from 4 mg/L to 17.5 mg/L.

Algal blooms were observed in some lagoons and one lagoon had a chlorophyll *a* concentration of 757 mg/L (Figure 15).

Figure 15 Algal bloom in Darwin lagoon (from Schult and Welch, 2006)

In summary algal blooms have a high likelihood of occurring in permanent waterbodies during the dry season. During the dry, nutrient concentrations are likely to increase, minimal flow rates, and ample sunlight and water temperature create ideal conditions for algal blooms.

5.2.6 Mosquitoes

Mosquitoes are responsible for the transmission of a number of arboviral diseases the most common in the NT are Ross River fever, and malaria (DHCS, 2001). The NT government actively controls mosquitoes, especially when outbreaks of arboviral diseases occur.

Wetlands create standing water bodies which are potential breeding grounds for mosquitoes. In particular, wetland drying presents the risk of mosquito breeding, as it can lead to isolated stagnant pools as a wetland dries out.

Mosquito control will be an important consideration in the design of any wetland type in the Darwin Region. The design will need to carefully consider issues such as the likelihood of the design to create disconnected shallow pools, promotion of mosquito larvae predators, vegetation type and edge type.

Two key management measures are:

- Permanent pools can support mosquito predators – e.g. small native freshwater fish.
- Waterbodies can be edged with steep banks or even vertical walls to prevent the formation of isolated stagnant pools.

5.2.7 Waterlogged soils

Waterlogged soils are a problem in the Darwin Region during the wet season. This will be an important consideration when designing wetlands for low-lying areas in the region. Most of the proposed wetland design options outlined in this section involve lining the wetland with an impervious barrier. This could potentially impede wet season groundwater flows, creating local groundwater mounding and lead to detrimental impacts on the wetland itself or surrounding structures.

A map of waterlogged soils in the Darwin Region is shown in Figure 16, indicating the extent of the issue.

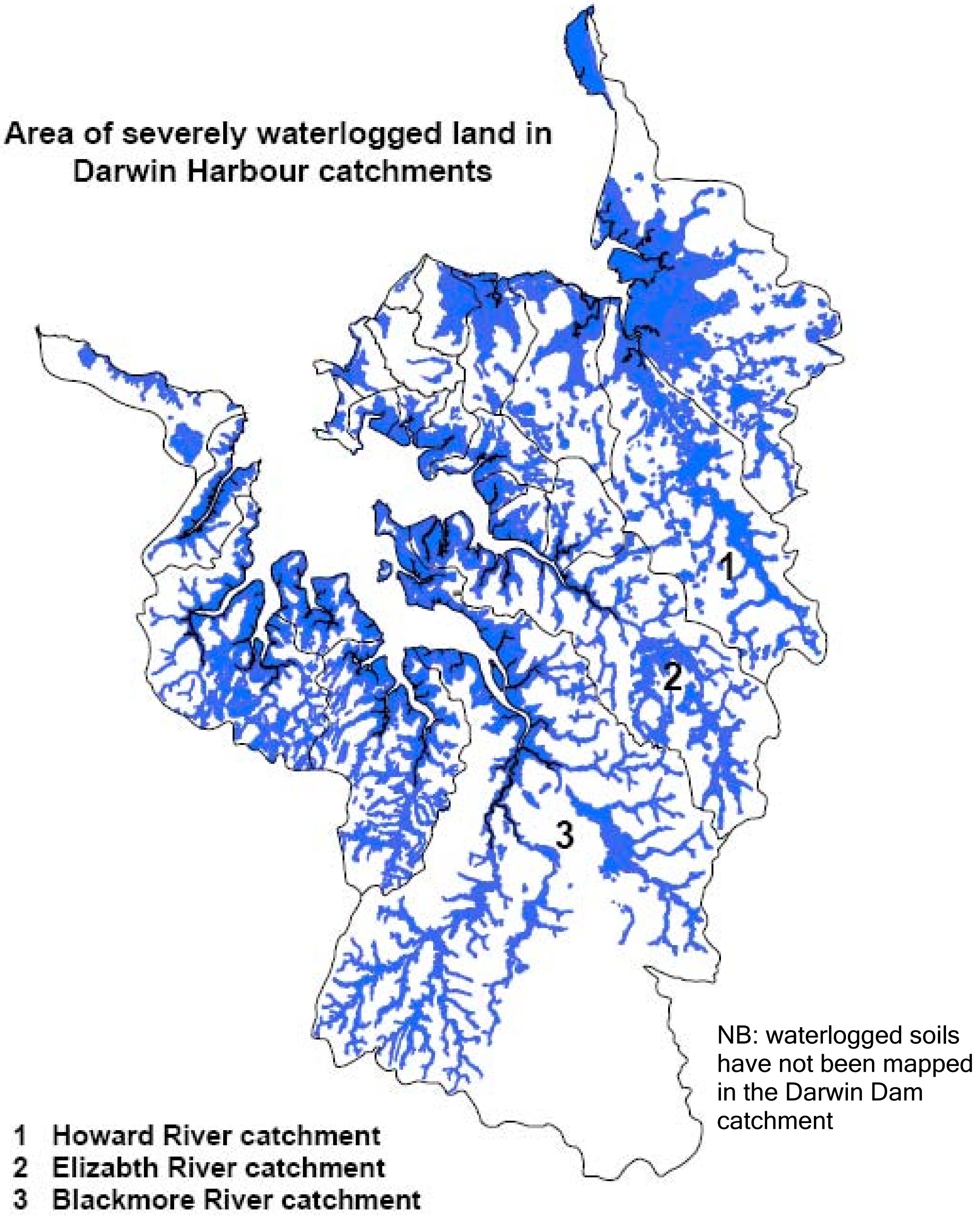


Figure 16: Waterlogged soils in the Darwin Region (Water Monitoring Branch 2005, Map 3.1, p.10)

5.3 Potential wetland solutions

Wetlands in tropical climates may need to persist for four to five months with very little input of water. The following designs aim to overcome this period of drought by either:

a) Holding enough water so that water remains in the wetland at the end of the dry season thus ensuring the persistence of aquatic plants and animals or,

b) Providing enough soil moisture so that the plants selected for the treatment device can survive the dry season.

Three basic design options for adapting stormwater wetlands to the tropical climate of the Darwin Region are outlined this section:

- Conventional permanent waterbody wetlands topped up with secondary water supply
- Ephemeral wet/dry wetlands
- Ephemeral wetlands with deep water zones

5.3.1 Conventional permanent waterbody wetlands

Conventional wetland design principles aim to maintain a permanent waterbody which has well vegetated surfaces to promote adsorption, sedimentation, biological uptake and filtration.

Conventional wetlands can only be maintained in the wet/dry tropics if they are topped up with a secondary supply of water, such as bore water, stored stormwater, recycled wastewater or potable water during the dry season. Initial modelling has shown that permanent waterbody wetlands will need to be topped up with 1 kL/m^2/yr during the dry season, assuming that the water level can vary by 0.1m before it needs to be topped up.

Furthermore, if designed using approaches adopted for southern Australia, these wetlands are likely to be at maximum extended detention depth during a large portion of the wet season. It will be necessary to consider one or all of the following design modifications to ensure vegetation can be sustained over the wet season (i.e. vegetation is not drowned):

- Reduce the total depth of the wetland
- Ensure the extended detention depth is 0.5 m or less
- Reduce the notional detention time from 72 hours to 24-48 hours

These modifications would have an effect on treatment performance.

5.3.2 Ephemeral Wet/Dry wetlands

Wetland design based on principles from the temperate zones of Australia, including shallow permanent pools of less than 0.5 m and 72 hour extended detention with a depth of up to 0.5 m will inevitably dry out in the wet/dry tropics. This may be an acceptable solution, provided that certain design issues can be resolved.

A conceptual diagram of an ephemeral wet-dry wetland is shown in Figure 17. Design issues are discussed below. The conceptual design includes the following features:

- The wetland is shown as being lined with a relatively impervious clay layer. This is suggested to maximise the retention of water into the start of the dry season, and retain any dry season flows from urban catchments.
- Topsoil would need to be included above the impervious liner; a minimum of 300 mm is required for plant growth.

- The wet season water level is shown as approximately 1.0 m in the deepest part of the wetland, and 0.2-0.5 m in the shallowest part of the wetland.

- The species composition in the wetland would change with the seasons:

  - During the wet season, the deep water would be populated by submerged macrophytes, with shallower zones populated by emergent macrophytes such as *Phragmites*, *Eleocharis* and *Bolboschoenus*. The shallowest part of the wetland would be populated with floodplain grasses such as *Pseudoraphis*, *Oryza* and *Leersia*. Zones of vegetation would be similar to those outlined in section 3.1 and Figure 6 provides a guide to establish planting in each of the zones.

  - During the dry season, wetland vegetation that is relatively shallow rooted and unable to access groundwater will die off. Macrophytes would be replaced with terrestrial species of annual grasses, herbs and sedges as the water recedes. However typically the percentage cover of the dry season annuals are lower than that during the wet season. This low percentage of cover will have an impact on aesthetics and erosion and will be a key component of the urban design of wetlands.

It is expected that the changes between wet season and dry season vegetation could take place as a natural process. Some species selected will survive throughout the wet and dry seasons, such as grasses, *Eleocharis*, *Phragmites* and *Bolboschoenus*. Survival mechanisms of these plants include temporary dormancy, fightback and subsequent regrowth from plant tubers, and phenotypic adaptation. During the wet season aquatic macrophytes will grow from seed deposited in the previous wet season. The conditions for germination are important and the factors that impact on germination are discussed in section 3.2.2. The early wetting of a dry wetland needs to be controlled to ensure that conditions are right for germination. For example *Oryza* will produce no seedlings under inundated conditions.

Figure 17 is a generalised cross-section indicating that the ephemeral wet-dry wetland should include deep and shallow water zones. These zones should be located in series, to encourage plug flow and ensure that all flows pass through the full range of zones. Wet-dry ephemeral wetlands could be designed in a range of configurations, for example they could be located along drainage lines, to retain existing wetland or waterway vegetation that is typically inundated during the wet season. The design of these systems could include a series of shallow bunds that run perpendicular to the drainage line. Stormwater runoff would be retained behind the bunds.

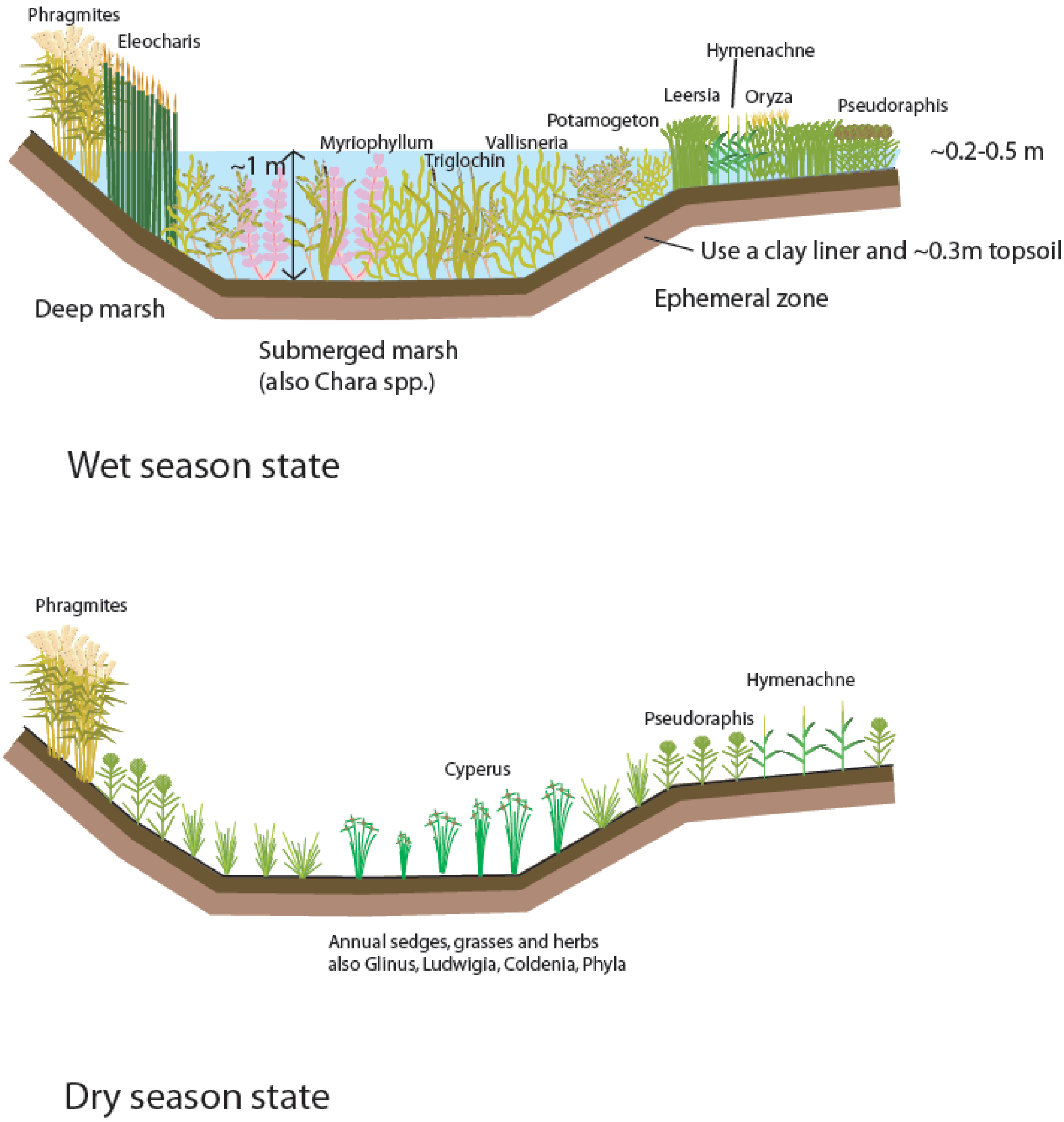


Figure 17: Conceptual diagram of an ephemeral wet-dry wetland

The following issues will need to be addressed further during detailed design to ensure a robust ephemeral wet/dry wetland design:

- Good treatment performance is assisted by dense vegetation cover. Further investigation is needed to confirm whether it is possible in a constructed wetland to rely on a natural switching between wet and dry season species at the change in seasons. This process may rely on having a suitable seed bank available in the topsoil used in the wetland. Alternatively a hydraulic solution may be required which could either bypasses the wetland or retain all flows within a designated zone to allow the wetland vegetation to reestablish.

- The optimal detention time and hydrologic effectiveness of the wetland. More detailed modelling needs to be undertaken to determine the optimal hydraulic functioning of the wetland. This will impact on the operation of the depth and particularly 'extended detention' during the wet season.

- Careful design would be required to ensure that these wetlands do not encourage mosquito breeding in shallow pools as they dry out.

- Further investigation is also needed into weed management, to ensure that the ephemeral wet/dry wetlands are as resistant as possible to weed invasion. Vegetation density in ephemeral wetlands is likely to fluctuate over the seasons, and the risk of weed invasion would need to be managed, particularly at times where vegetation density is low, providing an opportunity for weed establishment. The times of particular concern are at the change in seasons when one type of vegetation is dying back and another is re-establishing.

- Magpie geese feed on the tubers of grass and sedge species such as *Eleocharis* spp during the wet season. Disturbance by geese may result in the loss of *Eleocharis* plants. The disturbance of these plants may leave wetlands susceptible to invasion by weeds such as paragrass.

5.3.3 Ephemeral wetlands with deep water zones

Within the context of an ephemeral wet/dry wetland, it may be beneficial to retain a deep water zone in a region within the ephemeral wetland, to

- Create a habitat for mosquito larvae predators

- To improve landscape aesthetics and

- To provide habitat and refuge zone for submerged aquatic and macrophytes during the dry. This refuge will then assist the vegetation to rapidly colonise the ephemeral zone at the beginning of the wet season.

This deep water zone should have a large section of open water, which would be designed to retain water for the whole dry season.

Two potential options for incorporating permanent water are illustrated below. Each includes at least one section of 2.0 to 2.5 m depth, expected to hold water throughout the dry season, and another shallower section of 0.5 to 1.0 m that would only be inundated in the wet season. The shallower zones would be where the majority of the treatment would occur, as there would be more contact with vegetation in these zones.

In both options, the deep water zone would be a lined pond populated with vegetation from floating mat communities and fringe permanent communities as outlined in section 3.2 as well as submerged macrophytes such as *Triglochin*, *Vallisneria*, *Chara*, *Myriophyllum* and *Potamogeton* . The shallow water zone would be made up of:

- <u>Option 1: macrophyte wetland</u> supported on a base of pervious soil media (sandy clay loam approximately 15 to 30% clay). This design assists wetland plants to survive the dry season by creating a perched water table that permeates the macrophyte planting media. Plant roots will be able to access water in the planting media during the dry season.

- <u>Option 2: melaleuca wetland</u> supported either on in-situ or imported soils. During the wet season, it is expected that aquatic macrophytes would spread from the deep pond to populate the melaleuca wetland, then during the dry season the aquatic species would retreat to the pond, and annual terrestrial species including sedges, herbs and grasses would replace them amongst the melaleucas. Melaleucas and some grasses can tolerate up to six months of inundation in water depths up to 1 m.

These options are illustrated in Figure 18 and Figure 19, which are followed by a discussion of the key design issues that would need to be resolved to prove the feasibility of each option.

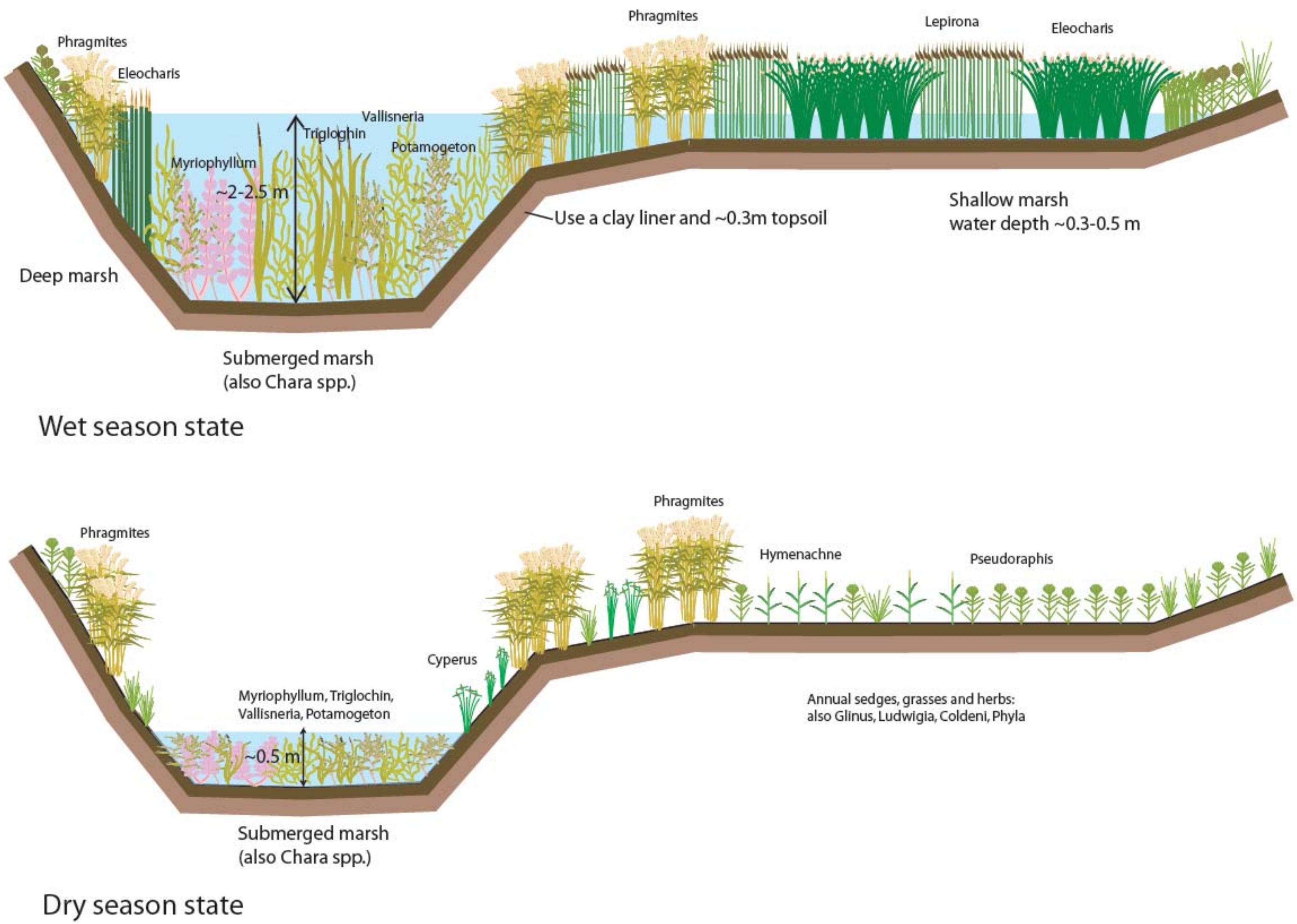


Figure 18: Conceptual diagram of an ephemeral macrophyte wetland with a deep water zone

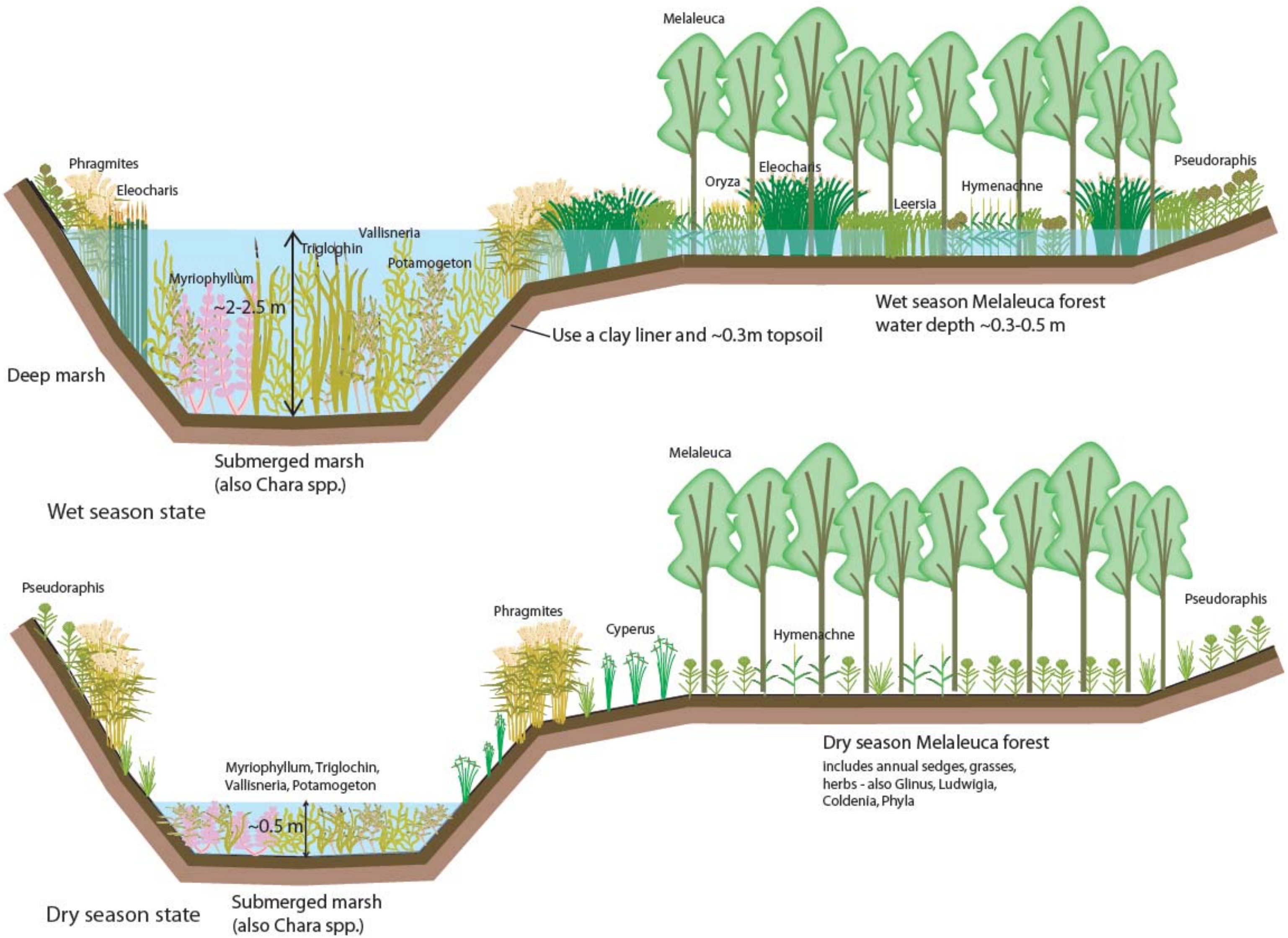


Figure 19: Conceptual diagram of an ephemeral melaleuca wetland with a deep water zone

The following issues will need to be addressed for the ephemeral wetland with deep water zone to be proven feasible:

- Depth of the liner under the ephemeral zone. The liner will be required to ensure excessive water loss does not occur. The deeper the liner the greater the volume of soil water that will be available to the ephemeral zone. .
- It may not be necessary to line the whole wetland footprint. For example, under the melaleuca wetland, interaction with the local groundwater table could help sustain the deep-rooted melaleuca through the dry season. This may need to be an issue that is considered on a site-specific basis.
- The proportion of surface area that is dedicated to deep pool.
- Further investigation is needed to determine whether a natural transition between wet season aquatic macrophytes and dry season terrestrial species is likely to occur.
- The die off of vegetation at the beginning of the dry season needs to be considered. Plant die off can lead to mats of detritus, higher nutrients levels and eutrophic conditions, as evidenced by studies into Darwin lagoons (Lloyd, 2006).These conditions strongly favour the growth of algal blooms. Removal and harvesting of plant die off may be necessary.
- It has been estimated that over a typical dry season, an open water pool will draw down between 0.75 m and 1.25 m, as shown in Figure 20. The deep pond will thus need to have a depth of at least 1.5 m to ensure that it does not dry out. If a minimum water level of 0.5m is desired the water level will need to have a minimum depth of 2m. This depth does not account for loss of water to evapotranspiration. The pond will not be able to sustain fringe vegetation over this water level variation and hence the edge treatment of the pond will need to be considered in the design.
- It may be possible to top up the pond with a non-potable source of water to ensure a constant water level. The volume of water required for top up in a typical dry season has been estimated at 1 $kL/m^2/yr$.

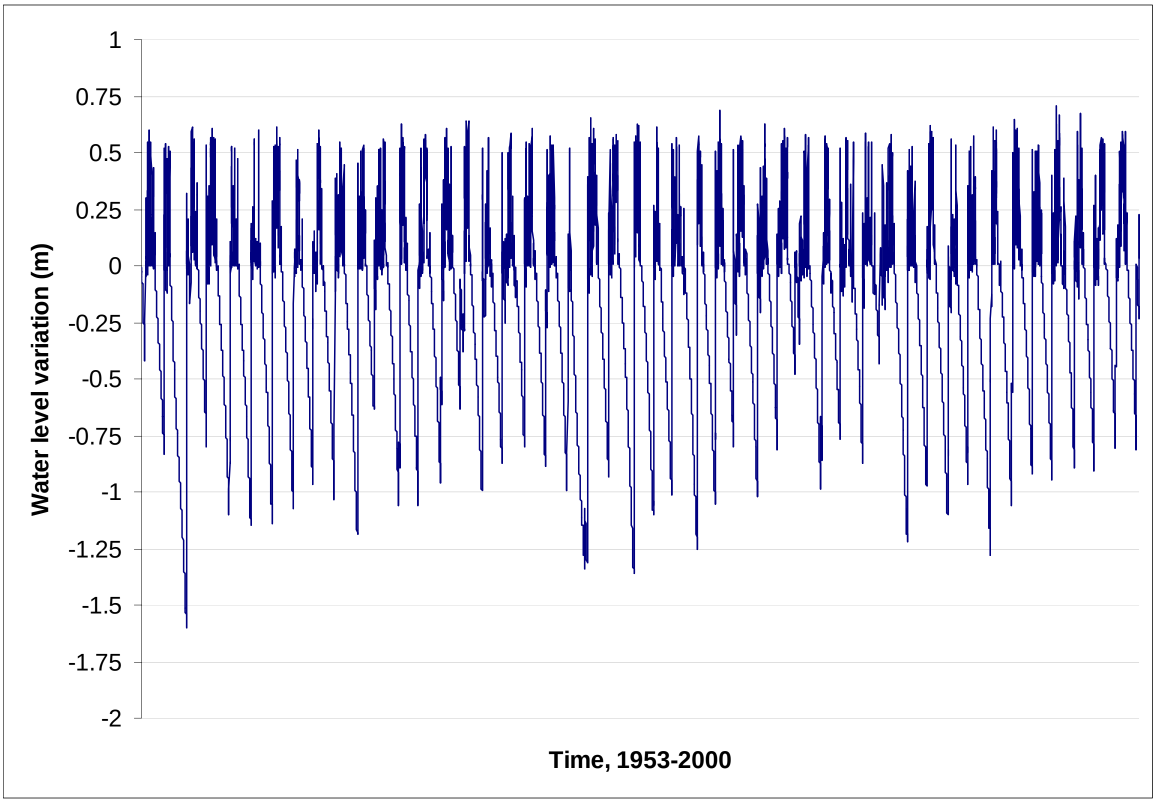


Figure 20: Water level variation in the deep water zone

5.4 Vegetated stormwater treatment ponds

As an alternative to a wetland, a vegetated pond could provide a suitable stormwater treatment option in the Darwin Region. A conceptual diagram of a stormwater treatment pond is shown in Figure 21. The design includes the following features:

- The pond is lined and is deep enough so that it can retain some permanent water in the dry season. The water that remains provides a refuge for aquatic organisms during the dry season.
- During the wet season the pond fills up and submerged macrophytes proliferate. The depth of the pond is sufficient to ensure that water lilies do not dominate the water surface.

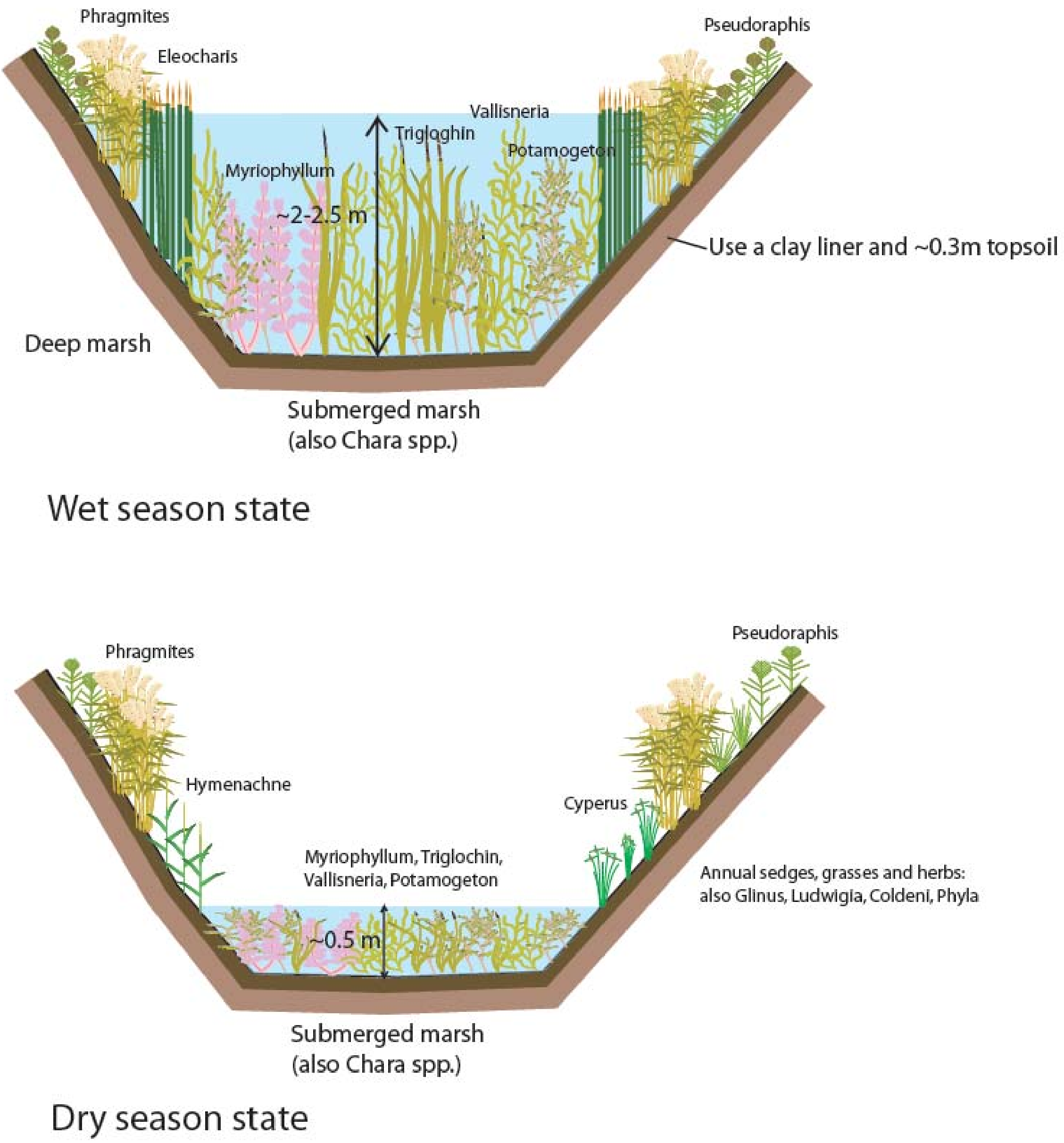


Figure 21: Conceptual diagram of a vegetated stormwater treatment pond

The following issues will need to be addressed for the vegetated stormwater treatment pond to be proven feasible:

- The conceptual design involves a very deep system, which would need to be carefully designed in an urban environment. Batter slopes need to consider public safety, planting, and amenity in the wet and dry seasons. The pond footprint would be affected by the gradient of the batter slopes.
- Any vegetation along the fringe of the batter slopes is likely to be ephemeral and the design considerations for wet-dry zones are similar to those outlined in section 5.3.2 and 5.3.3. Top-up of the ponds using potable water or an alternate water source could be considered.
- The design of the pond would need to ensure that the pond has a high hydraulic efficiency and that there is no short circuiting
- The treatment performance of a vegetated pond in the wet/dry tropics

- Required detention time within the pond and the impact of this on the permanent pool depth and extended detention

- The dry season drawdown for stormwater wetlands may be less than natural wetlands because of the effective delivery of water from impervious urban surfaces, relative to natural catchments. The dry season water level may therefore not be as low as indicated in Figure 21.

- Appropriate sizing would need to be determined. Ponds are generally less efficient than wetlands for stormwater treatment, as there is less contact between stormwater and vegetation.

- Turbidity may be an issue in deep ponds and it could limit photosynthesis.

6 Bioretention Systems

6.1 Conventional stormwater bioretention systems

Bioretention systems can be configured as basins (or rain gardens), planter boxes, street trees, or in the base of swales. Bioretention systems are vegetated areas where runoff is filtered through a filter media layer (e.g. sandy loam) as it percolates downwards. It is then collected in a drainage layer via perforated under-drains and flows to downstream waterways or to storages for reuse. Bioretention basins typically use temporary ponding of 0.2-0.4 m depth above the filter media surface to increase the volume of runoff treated through the filter media. Flows above the design flow are conveyed through overflow pits or bypass paths. This has the advantage of protecting the filter media surface from high velocities that can dislodge collected pollutants or scour vegetation.

Vegetation plays a key role in bioretention systems. The surface is densely planted with ground level grasses and rushes and may also contain selected tree and shrub species. The agitation of the surface of the bioretention basin caused by movement of the vegetation and the growth and die off of root systems prevents accreted sediments clogging the filtration media. Beneath the surface, vegetation provides a substrate for biofilm growth within the upper layer of the filter media. Vegetation facilitates the transport of oxygen to the soil and enhances soil microbial communities which enhance biological transformation of pollutants.

Bioretention basins are generally not intended to be 'infiltration' systems that discharge from the filter media to surrounding in-situ soils. Rather, the typical design intent is to recover stormwater at the base of the filter media in perforated under-drains and discharge to receiving waterways or to storages for potential reuse. In some circumstances however, where the in-situ soils allow and there is a particular design intention to recharge local groundwater, it may be desirable to allow stormwater to infiltrate from the base of a filter media to underlying in-situ soils.

A typical bioretention system is shown in Figure 22. Some examples of bioretention systems from around Australia are shown in Figure 23.

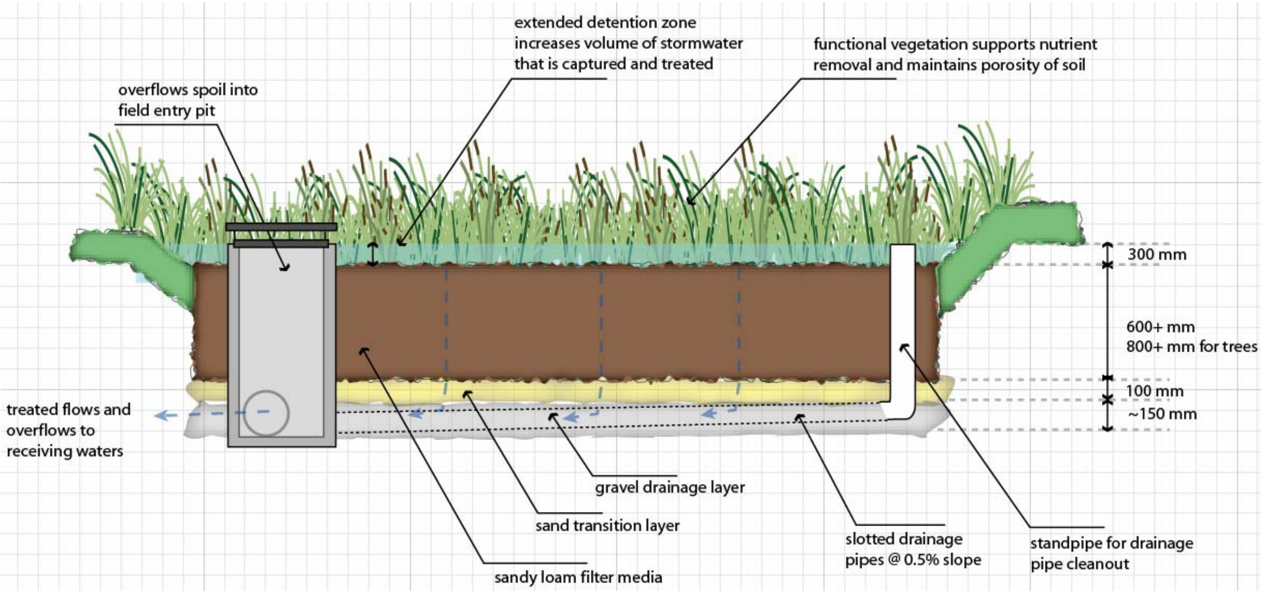
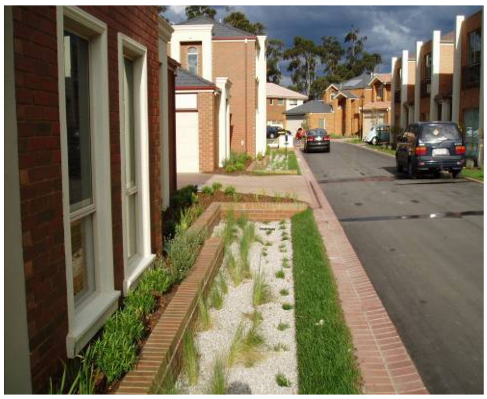


Figure 22: Typical section through bioretention basin

Sydney University

Victoria Park, Sydney

South Australian Museum, Adelaide



Baltrusol Estate, Melbourne

Figure 23: Examples of bioretention systems at various scales

In a bioretention system, treatment of the stormwater occurs both on the surface amongst the vegetation and within the filter media. When larger storm inflows cause temporary ponding on the surface of the basin, pollutants are removed from the stormwater through sedimentation and particulate adhesion onto the stems and leaves of the vegetation. As stormwater percolates through the filter media, fine particulates and some soluble pollutants are removed through processes such as adhesion on to the surface of the filter media particles, biological transformation of pollutants by biofilms growing on the surface of the filter media particles, and biomass uptake of nutrients and metals through the root systems of the vegetation growing in the system.

The nature of bioretention systems, being planted soil profiles, means there is a reasonable amount of flexibility regarding the size, shape and location of the systems. As such, there are opportunities to integrate bioretention systems as landscape features throughout the urban environment.

Key design considerations for bioretention systems are outlined in Table 7.

Table 7: Design considerations for bioretention systems

Design issue	Key considerations
Landscape design	Bioretention systems are predominantly located within public areas, such as open space or within streets, which provide a primary setting for people to experience their local community and environment. It is therefore necessary for bioretention systems to be given an appropriate level of landscape design consideration to complement the surrounding landscape character. The landscape design of bioretention systems must address stormwater quality objectives whilst also being sensitive to other important landscape objectives such as road visibility, public safety and community character and habitat.
Hydraulic design	The correct hydraulic design of bioretention basins is essential to ensure effective stormwater treatment performance, minimise damage by storm flows, and to protect the hydraulic integrity and function of associated minor and major drainage systems. The following aspects are of key importance: • The finished surface of the bioretention filter media must be flat to ensure even distribution of flows and avoid scouring or rutting of the surface • Temporary ponding (i.e. extended detention) over the surface of the bioretention filter media should be created through the use of raised edges • Distributed inflows should be encouraged, so as to limit the risk of scour and erosion at inlets • Where possible, the overflow pit or bypass channel should be located near the inflow zone to prevent high flows passing over the surface of the filter media. If this is not possible, then velocities should be minimised to avoid scouring of the filter media and vegetation. • Where the field inlets in a bioretention system are required to convey the minor storm flow (i.e. is part of the minor drainage system), the inlet must be designed to avoid blockage, flow conveyance and public safety issues. • For streetscape applications, the design of the inflow to the bioretention basin must ensure the kerb and channel flow requirements are preserved
Exfiltration	Bioretention basins can be designed to either preclude or promote ex-filtration of treated stormwater to the surrounding in-situ soils. When considering ex-filtration to surrounding soils, the designer must consider site terrain, hydraulic conductivity of the in-situ soil, soil salinity, groundwater and building setback.

Design issue	Key considerations
	To preclude ex-filtration, the bioretention basin may need to be provided with an impermeable liner around the base and sides of the drainage layer (unless the in situ soils are relatively impermeable). Flexible membranes or a concrete casting are commonly used to prevent excessive ex-filtration. Ex-filtration of treated stormwater to the surrounding soils can be encouraged at sites where the in situ soils have a higher permeability than the filter media and the site conditions are suitable for infiltration. A liner may be required around the sides of the bioretention system to prevent short-circuiting of the system.
Vegetation types	Vegetation is required to cover the whole bioretention filter media surface, be capable of withstanding minor and major design flows, and be of sufficient density to prevent preferred flow paths, scour and re-suspension of deposited sediments. Ground cover vegetation (e.g. sedges and tufted grasses) is an essential component of bioretention basin function. Generally, the greater the density and height of vegetation planted in bioretention filter media, the better the treatment provided especially when extended detention is provided for in the design.
Filter media	Selection of an appropriate bioretention filter media is a key design step that involves consideration of the following three inter-related factors: • Saturated hydraulic conductivity required to optimise the treatment performance of the bioretention system, given site constraints and available filter media area. • Depth of extended detention provided above the filter media. • Suitability as a growing media to support vegetation (i.e. retains sufficient soil moisture and organic content). Bioretention media can consist of three layers. In addition to the filter media required for stormwater treatment, a drainage layer is also required to convey treated water from the base of the filter media into the perforated under-drains. The drainage layer surrounds the perforated under-drains and can be either coarse sand (1 mm) or fine gravel (2-5 mm). If fine gravel is used, a transition layer of sand must also be installed to prevent migration of the filter media into the drainage layer and subsequently into the perforated under-drains.
Mulch	To help prevent erosion, discourage weed establishment and to improve aesthetics of bioretention systems, it is common to use a rock mulch or similar non-buoyant mulch on the surface of the bioretention system. Mulches can also help bioretention systems maintain soil moisture between rainfall events.
Traffic controls	Another design consideration is keeping traffic and building material deliveries off bioretention systems, particularly during the construction phase of a development. If bioretention basins are driven over or used for parking, the filter media will become compacted and the vegetation damaged. As they can cause filter media blockages, building materials and wash down wastes should also be kept out of the bioretention basin. To prevent vehicles driving on bioretention basins, and inadvertent placement of building materials, it is necessary to consider appropriate traffic control solutions as part of the design. These can include dense vegetation planting that will discourage the movement of vehicles onto the bioretention basin or providing physical barriers such as bollards and/ or tree planting. Streetscape bioretention systems must be designed to satisfy local authority requirements with respect to traffic calming devices within particular street or road reserve widths. Where bioretention is incorporated into traffic calming or control

Design issue	Key considerations
	devices, or directly adjacent to mountable kerbs, consideration should be given to protection of the area immediately behind the kerb where vehicles are likely to mount the kerb.
Services	Bioretention basins or cells located within road verges or within footpaths must consider the standard location for services within the verge and ensure access for maintenance of services without regular disruption or damage to the bioretention system.

6.2 Design considerations in the wet/dry tropics

6.2.1 Vegetation selection

Due to the wet and dry seasons in the Darwin Region, bioretention systems will operate substantially differently to those in temperate regions. During the wet season, the bioretention systems will receive large volumes of consistent rainfall while during the dry season the bioretention are likely to remain dry if no anthropogenic source of water is added.

Rainfall analysis of hourly rainfall at Darwin Airport was undertaken for 7 years of data from 1993 to 2000. To understand whether rainfall followed a regular diurnal pattern, e.g. afternoon thunderstorms, the number of times rainfall occurred during a particular hour was analysed. Figure 24 shows that rainfall occurs relatively evenly throughout the day, with no particular diurnal pattern.

Figure 25 shows that rainfall also predominantly occurs in sharp intense bursts, with 50% of raindays having rain falling on 5 hours or less of the 24 hours during the day. In contrast only 25% of raindays are likely to have rain for 15 to 24 hours of the day.

This pattern of rainfall will allow bioretention systems to drain in between rainfall events, and ensure that ponding only occurs temporarily after a rainfall event. Bioretention systems are typically constructed using free draining soils. Unlike wetlands, bioretention systems are typically designed to drain completely after the cessation of rainfall. A typical hydraulic conductivity of bioretention systems is likely to be 200 to 400 mm/hr; therefore bioretention systems can drain within hours after a storm event. During the dry season, bioretention systems will dry out relatively quickly due to the nature of the free draining soils. Therefore, vegetation selection must be carefully considered to ensure the bioretention vegetation can be sustained during long periods of little or no rainfall. It is expected that without irrigation, the majority of the bioretention vegetation will die back during the dry season, but should be capable of re-establishment at the start of the next wet season.

Anecdotal evidence has suggested that in some locations, there may be significant low flows during the dry season from excess irrigation runoff. These low flows from subsoil drainage and irrigation surface runoff may be sufficient in some cases to maintain the vegetation in the bioretention system. Furthermore these low flows potentially carry high concentrations of nutrients from fertiliser application, which the treatment system will help to prevent reaching the downstream aquatic environment.

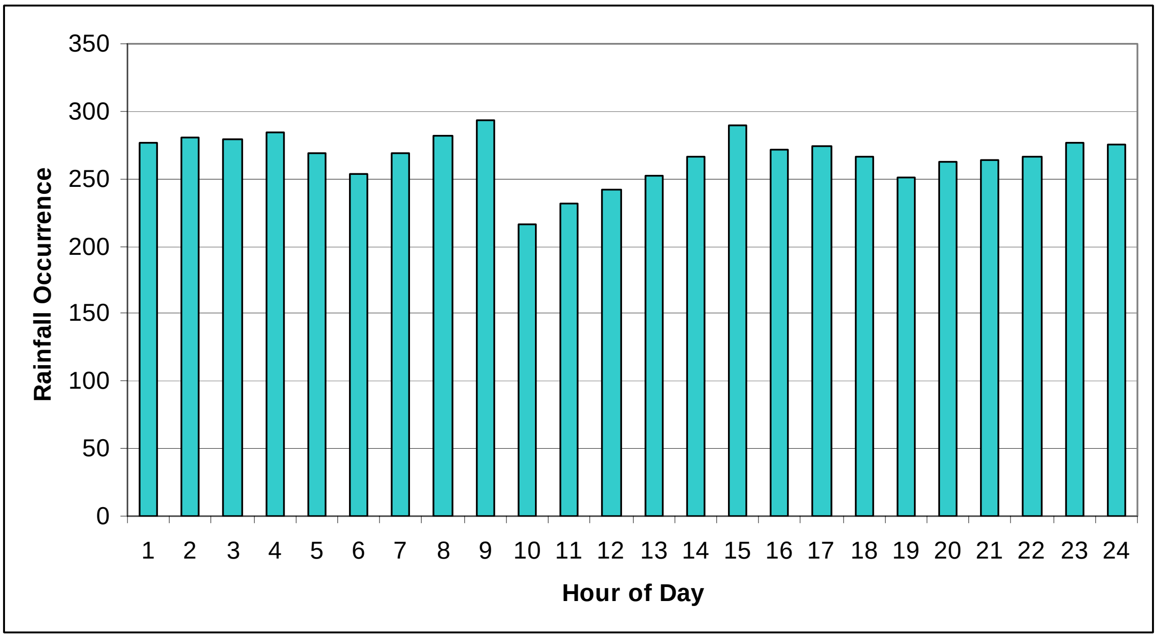


Figure 24 Diurnal Rainfall Pattern

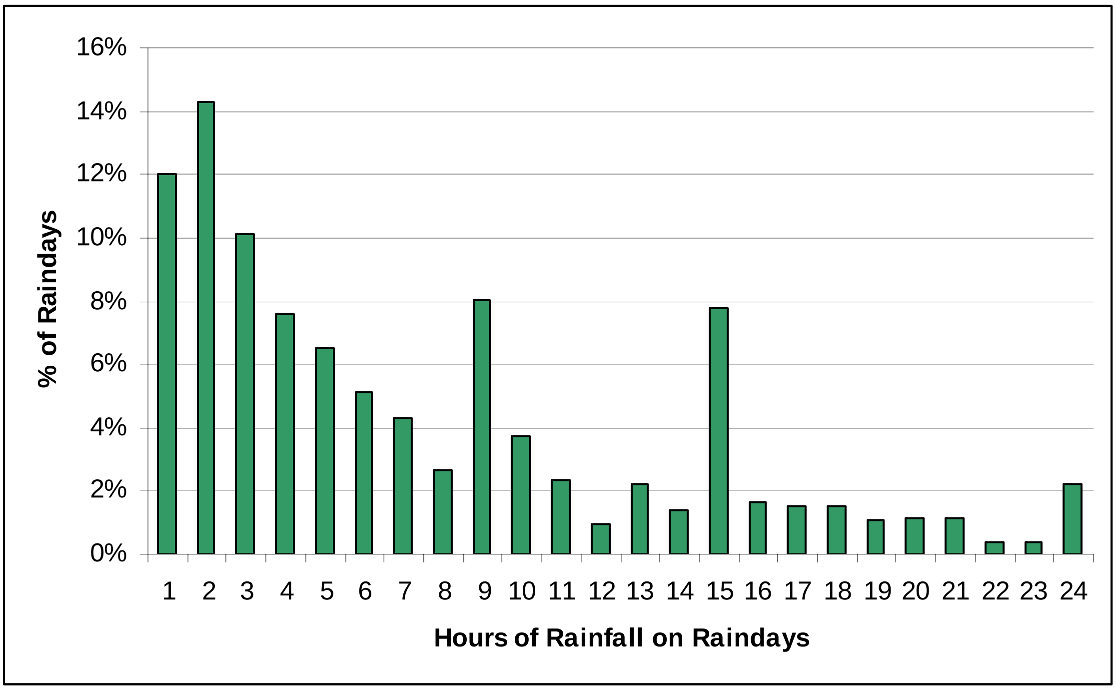


Figure 25 Analysis of rainfall duration

6.2.2 Seasonal performance

Both prolonged drying during the dry season and continuous loading during the wet season could affect bioretention performance.

Zinger et al (2007) studied the effects of prolonged drying (periods of 1-8 weeks) on bioretention systems and found that conventional bioretention systems suffer a significant reduction in treatment performance after drying, and may become a source of nitrogen after two or more weeks of drying. After re-wetting, Zinger et al (2007) also found that conventional bioretention systems may take as long as the antecedent dry period to recover their pollutant removal performance. In

the Darwin Region, bioretention systems will dry out over the dry season, and it will be important to ensure that their performance recovers relatively quickly at the start of the wet season.

The performance of bioretention systems under continuous loading (as would occur during the wet season when rainfall is daily) is another potential issue. It may cause issues with the clogging of the filter media, especially due to growth of biofilms or algal mats, and a reduction in hydraulic conductivity over the season. The physical and chemical processes within bioretention systems may also be affected by continuous loading.

6.2.3 Coarse sediment management

Bioretention design for Darwin will need to consider coarse sediment management. There is a possibility that the basins could be compromised by the first storm events when there is little vegetation cover. If the sediment load is large, there is a risk that vegetation may be smothered and depositional fans may form reducing the infiltration rate of the bioretention basin.

To mitigate these effects, pipe outlets to the bioretention basins can be designed to discharge into coarse sediment collection forebays. These forebays are designed:

- To remove particles that are 1 mm or greater in diameter from the 3 month ARI storm event.
- With large rocks for energy dissipation and be underlain by filter material to promote drainage following a storm event.
- With trash collection grilles.

6.2.4 Soil and groundwater interaction

As outlined in Table 7, bioretention systems are often lined with an impermeable barrier to ensure water is captured in the subsurface drainage system and directed to the stormwater system or receiving environment. Where there is no risk of causing nuisance flooding downstream or damage to structures due to infiltration, the bioretention system need not be lined. A bioretention system that is not lined can promote infiltration into groundwater aquifers and may also effectively control the rise of a high unconfined shallow aquifer during the wet season. By providing a free draining sub soil drain, groundwater will be controlled by the bioretention system.

6.3 Potential bioretention solutions

Two basic options for adapting bioretention systems to the wet/dry tropical climate are outlined below.

6.3.1 Conventional bioretention systems

Conventional bioretention systems could operate effectively in the Darwin Region, providing some key issues are addressed. Some design options include:

- Allowing bioretention vegetation to die back during the dry season, which will need to be carefully integrated with the urban design and aesthetics of the landscape. Suitable vegetation, such as savanna vegetation should be chosen that can survive the dry season without complete die-off. Details on savanna vegetation communities are outlined in section 3.3
- Irrigation of the bioretention system during the dry season. If shallow rooted perennial vegetation which cannot withstand the long dry season are used in the bioretention system and the vegetation is to be maintained during the dry season it will be necessary to irrigate the bioretention system. A non potable source of water is preferable (i.e. harvested stormwater), however using a wastewater source that is high in nutrients is likely to compromise the bioretention system. There are a number of advantages to maintaining the bioretention system vegetation via irrigation, including the ability to cope with sediment and pollutant loads during the first rain events at the beginning of the wet season, reduced risk of wind blown erosion, and landscaping and aesthetic reasons.

- The use of trees and shrubs which are adapted to tropical savanna conditions, in an un-lined bioretention system. Subject to site-specific considerations, such vegetation would be able to access groundwater during the dry season. Shallow rooted grass and sedge species will 'die back' during the drought season and regenerate during the beginning of the wet season. Hence these bioretention systems will have the appearance of open woodland or forest during the dry season. This option is likely to require irrigation during its initial one or two dry seasons, until the vegetation is established. Unlined systems may not be appropriate at all sites, e.g. they should be avoided in areas with very high wet season groundwater levels. Trees may also be able to survive in shallow lined systems as rooting depths of savanna trees are often in shallow soils less than 1m deep as discussed in section 3.3. A conventional bioretention system with vegetation suitable for the Darwin Region is shown in Figure 26.

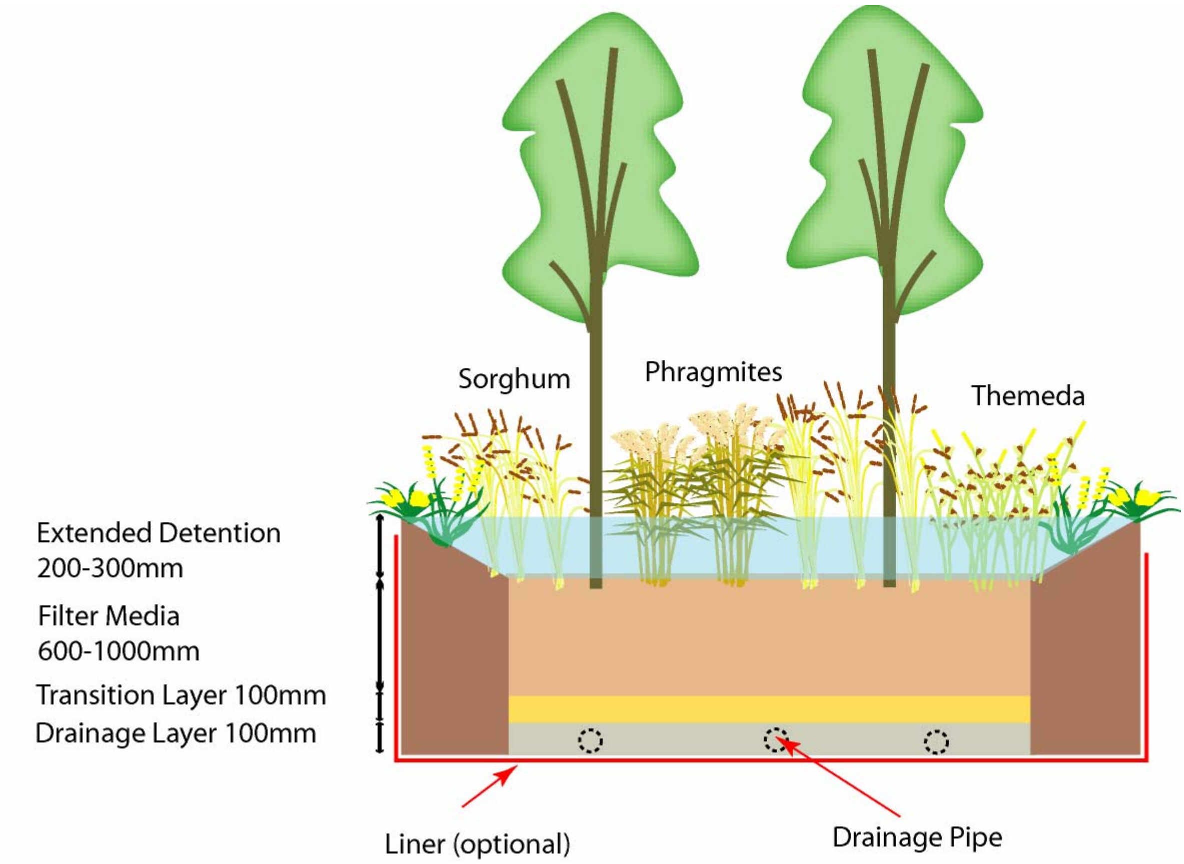


Figure 26: Conceptual diagram of a bioretention system

6.3.2 Saturated zone bioretention systems

The use of a saturated zone may be one way to overcome some of the issues associated with bioretention system drying. A saturated zone can be formed at the base of a bioretention system by using a riser pipe with the outlet level higher than the drainage layer. The saturated zone would hold water rather than draining freely, and would therefore provide a source of water to the plants during dry periods. The water in the saturated zone would be gradually drawn down via evapotranspiration. "Submerged anoxic zone" bioretention systems use this configuration, and also include a carbon source in the saturated zone, which helps promote denitrification.

Submerged anoxic zone systems are still at an experimental stage; however their design involves a relatively simple modification to a conventional bioretention system. They include an additional layer at the base of the bioretention system, below the filter media. Zinger et al (2007) used a 400 mm deep anoxic zone. The additional layer should be sandy loam (similar to the filter media) and should contain a carbon source (such as woodchips) to promote denitrification. Denitrifying bacteria occur in a small anoxic layer around the surface of the carbon source, and the stormwater passing through the system does not become anoxic itself.

Bioretention systems for the Darwin Region could be designed either:

- As a "submerged anoxic zone" bioretention system. It needs to be investigated whether these systems could function with a true anoxic zone under the high loading rates that would occur in the wet season.

- As a conventional system with a saturated zone (i.e. without a carbon source in the saturated layer).

A conceptual diagram of the latter system is shown in Figure 27.

As these bioretention systems are designed to retain some water, they could support plants for a longer period than fully drained bioretention systems. These systems may still require some irrigation to survive the entire dry season, as over a long period, evapotranspiration would consume the water within the submerged anoxic zone.

Recent research findings provide some indication as to how saturated zone bioretention systems may perform in the Darwin Region:

- Zinger et al (2007) found that experimental bioretention systems with a submerged anoxic zone retained better treatment performance after drying, and also recovered their full potential much faster after prolonged drying. However the longest period they tested was seven weeks, as the vegetation they used was unable to survive longer without water.

- Continuous loading of submerged anoxic zone bioretention systems has been tested at the laboratory scale. Kim et al (2003) studied unvegetated laboratory-scale systems under continuous loading for 37 days and found that nitrogen removal reached a steady state. The nitrogen removal performance depended on the loading rate (flow and concentration).

These findings may or may not apply to bioretention systems with a saturated, non-anoxic zone.

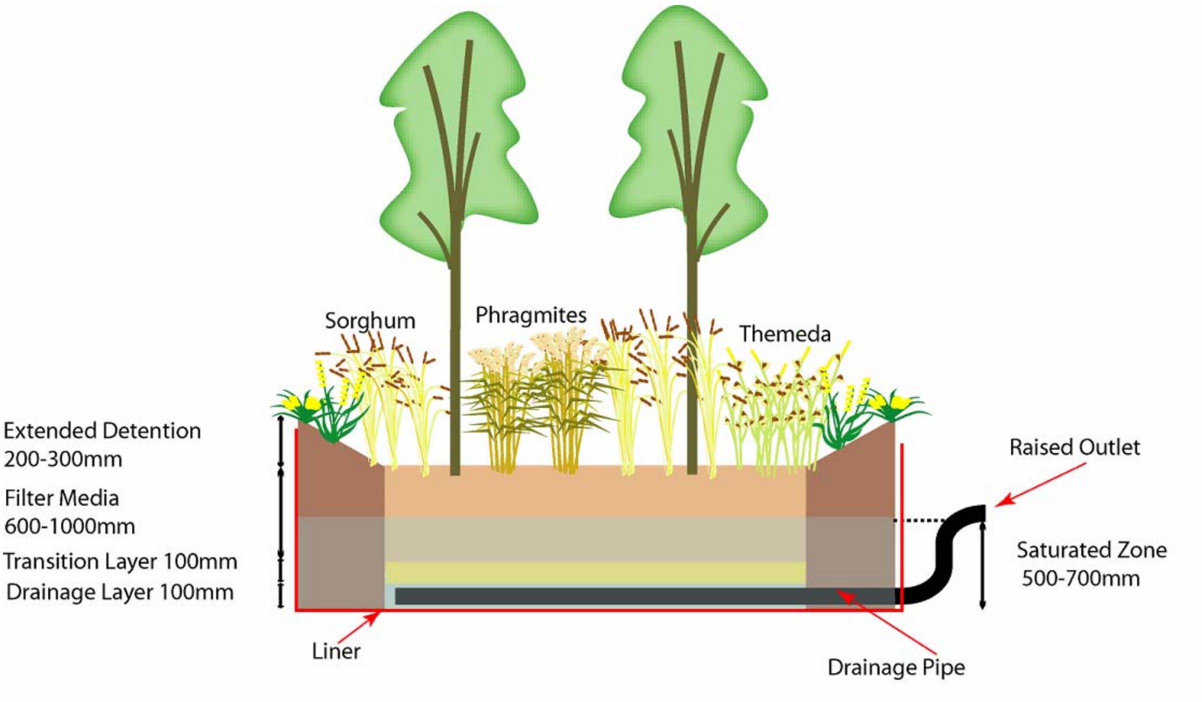


Figure 27: Conceptual diagram of a submerged anoxic zone bioretention system for the Darwin Region

7 Infiltration Systems

Infiltration systems promote the discharge of cleansed stormwater into the groundwater systems. Infiltration systems can reduce stormwater runoff and minimise pollution conveyance from urban catchments to lotic systems. Infiltration systems can also promote the recharge of aquifers, which otherwise may not occur in an urbanised impervious catchment.

7.1 Conventional infiltration systems

Infiltration systems are strongly influenced by soil permeability. As soil permeability decreases the effectiveness of infiltration as a runoff control strategy decrease unless there is a corresponding increase in retention devices which provide temporary storage of stormwater. Any infiltration strategy for the site so should take undertake geotechnical investigations including soil hydraulic conductivity tests.

There are four general types of infiltration systems.

- Leaky wells are used at the allotment scale and consist of a vertical perforated pipe with an open base. The perforations and open base are typically screened with a geotextile and a layer of gravel.

- Infiltration trenches are used at a range of scales and consist of a 1 to 1.5m deep trench filled with a porous media. Depending on the size of the system they can also contain a perforated distribution pipe to distribute the flows along the length of the trench. They are typically covered with backfill and can be covered with a range of surfaces

- Soakaways are similar to trenches but have a larger area and shallower depth. They can be used at a range of scales from the lot to suburb scale. A soakaway is shown in Figure 28.

- Infiltration basins are used in larger scale applications. They have detention volume provided within the basin. The basins are typically above ground and contain vegetated surfaces, of grass or natives.

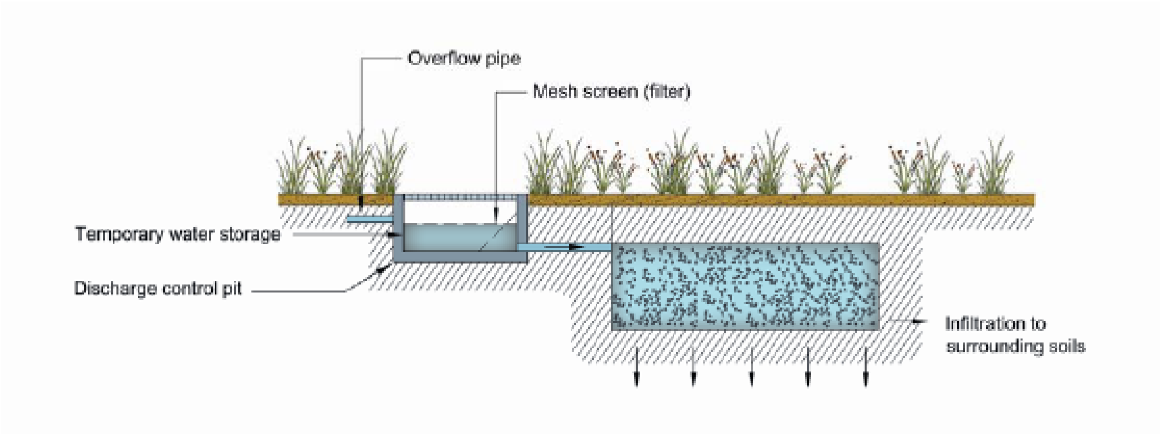


Figure 28 Soakaway cross section

Infiltration systems could be designed to work effectively with regional wetlands and potentially bioretention systems. An area of the treatment system could be dedicated to act as a recharge point.

Active aquifer recharge can also be promoted through the use of bores which directly pump water into a confined aquifer. This would only be suitable where capacity exists within an aquifer. This may be the case if aquifer extraction increases at the same time that urbanisation in the catchment reduces aquifer recharge. Hence, to ensure a robust design, the possibility of active aquifer recharge should be considered.

Infiltration systems can also be provided on the lot scale such as 'soakaways' for roof drainage as shown in the image to the right of a roof run-off rock filled infiltration zone in Parap, Darwin. Porous pavement can also be used as an onsite infiltration measure.

Infiltration needs to also carefully consider the issue of waterlogged soils. The practice of infiltration, combined with the removal of existing vegetation from the site for development, may exacerbate and accelerate 'waterlogging' of soils in the region.

Table 8: Design considerations for infiltration systems

Design issue	Key considerations
Application Scale	The type of infiltration system must consider scale of the contributing catchment area. Leaky wells and soakaways are suited to the lot scale while trenches and basins are suited to precinct and suburb scales.
Hydraulic design	Hydraulic design must take into account the volume and frequency of runoff discharged into the infiltration system. The infiltration rate of the in-situ soil is a key design issue. The design volume discharged through the infiltration device and the permeability of the soil determine the required detention volume. The design volume for a infiltration basin can be for a particular design storm, such as the 1 in 1 year ARI or based on hydrologic effectiveness and continuous simulation modelling (e.g. 80% of mean annual runoff volume).
Pre-treatment	Pre treatment of stormwater before infiltration has two different objectives: • Level 1: Removal of coarse sediment and gross pollutants to prevent blockage of the infiltration system • Level 2: Remove fine suspended solids and nutrients to protect groundwater quality and values are protected. In most cases Level 2 treatment will apply to pre-treatment requirements. In some situations, such as in large scale infiltration basins the pre-treatment can be incorporated into the infiltration device in the same process.
Terrain	Infiltration into sites on steep terrain can result in stormwater re-emerging downslope. This is particularly prevalent on shallow soils over rock and duplex soils. Infiltration on steep sites can also induce slope stability.

Design issue	Key considerations
In Situ Soil and Groundwater	Field measurement of in-situ soils is essential to inform the design of infiltration devices and detention volumes. In situ hydraulic conductivities in the range of 3.6 to 360 mm/hr (sand to sandy loam) are most suitable for infiltration. Soils with a saturated hydraulic conductivity less than this will require larger storage areas and are more susceptible to clogging. Infiltration should be avoided in areas with sodic/saline and dispersive soils and areas where the soil layer is underlain by a relatively impermeable rock or soil layer. The infiltration basin design needs to ensure that the base of the device is always above the groundwater table. It is generally recommended that the infiltration system is at least 1m above the high groundwater level. Where shallow groundwater is encountered, infiltration is not feasible.

7.2 Design considerations in the wet/dry tropics

The major determinant of the feasibility of infiltration systems in the Darwin region is the suitability of existing soils for infiltration. The geomorphology of the Darwin region is shown in Figure 29. The geomorphic units in the region which are likely to be most feasible for infiltration are the Plateaux unit. This unit has flat and undulating plains which contain sand to loamy soil types.

In some areas of Dissected Foothills and Dissected Uplands it may also be feasible to infiltrate stormwater however assessment of feasibility will require more detailed site specific analysis. These dissected areas contain hard indurate sandstone overlain by skeletal soils. These areas are more likely to be affected by the resurfacing of groundwater downslope of the infiltration site and cause slope instabilities.

The Littoral complex and Ephemeral Lagoon units are generally unsuitable for infiltration due to the proximity of the water table to the surface level. Thee regions are flat low lying areas with poorly drained floodplains, and water logged soils, as shown in Figure 16, and contain swamps, marshes and spring flow.

The issues associated with the design of vegetated infiltration systems are identical to the issues facing the design of bioretention systems. These issues are primarily associated with maintaining the vegetation through the dry season.

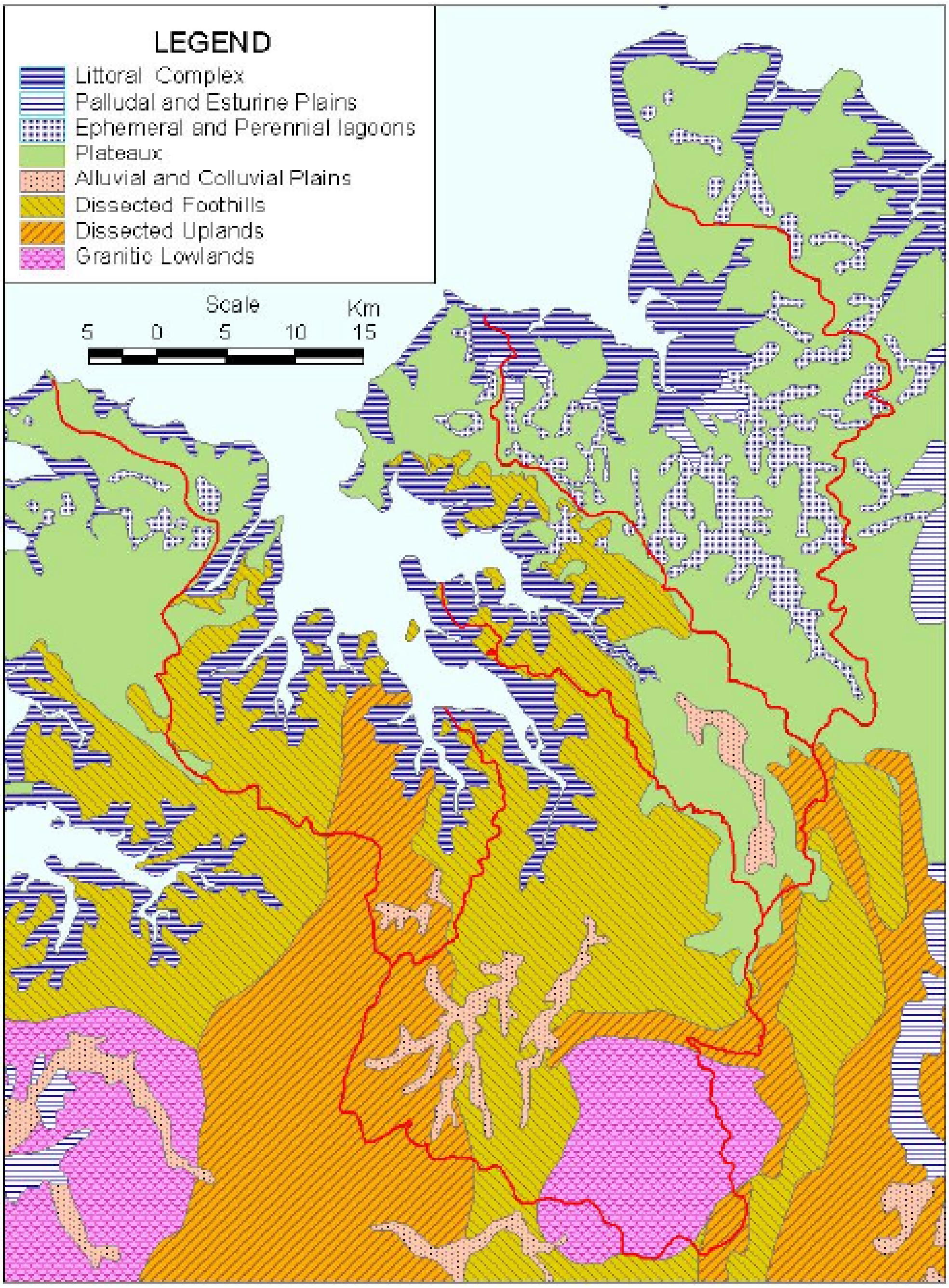


Figure 29 Geomorphology of the Darwin Region (Haig and Townsend, 2003)

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