Constructed wetlands can be an effective tool for treating urban and rural stormwater runoff. However, many locally built wetlands have been unsuccessful at removing nutrients, largely due to unsuitable designs for our local environment. For example, deep permeable sands and high groundwater are common on the Swan Coastal Plain making many traditional wetland designs (i.e. largely deep ponds) unsuitable for these conditions. Many water features in urban developments marketed as stormwater treatment constructed wetlands are permanent open water bodies with minimal fringing and instream native vegetation. Instead of treating stormwater runoff these water bodies can become sources of nutrients and create ideal habitats for algal blooms and weeds.
For optimal success at stormwater treatment, it is essential that constructed wetlands are carefully and specifically designed for local conditions, integrating the natural hydrologic regime*, local groundwater conditions, site geomorphology and important contaminant forms and transport pathways. For example, most of the naturally occurring wetlands on the Swan Coastal Plain are an expression of the high groundwater table. When the groundwater levels drop in summer, these wetlands dry out. This is a natural process and is beneficial to the nutrient recycling process and maintenance of the natural ecology of the wetland. Many of the constructed or modified wetlands on the Swan Coastal Plain should be designed to follow this natural hydrological regime, taking into consideration typical local conditions such as shallow groundwater and deep sands.

Ideally, wetland design should include a series of vegetated creeklines and basins for low flow treatment and a floodplain for the larger flow events. The design should attempt to mimic the natural system of seasonal pools and waterways on the Swan Coastal Plain. The existing topography should guide the position of the creekline, basins and floodplain.

Water sensitive urban design (WSUD) involves a continuous chain of treatment elements that address water quantity, water quality, water conservation and ecological objectives. Constructed wetlands can be useful as an end of catchment treatment measure where other in-catchment best management practices are not able to be implemented, or have been exhausted. One of the key principles of WSUD is to manage water quantity and quality at source which is generally regarded as a cost effective way to protect the receiving environment. However, end of catchment treatment elements are important particularly when retrofitting in existing urban environments. For further information on stormwater management and other best management practices, refer to the Department of Water’s Stormwater Management Manual for Western Australia (2004–7).

A project of the Swan River Trust’s Swan-Canning Cleanup Program involved an investigation into the design process to redefine appropriate design features for constructed wetlands specifically for the Swan Coastal Plain. The objectives of the project were to design a wetland to improve water quality and add value to the local environment. The principles behind this design and the design process form the basis of this River Science edition.

Why construct a wetland?

Many water bodies in our State have poor water quality, with high levels of nutrients: nitrogen (N) and phosphorus (P). Given ideal conditions, such as slow flowing water and full sunshine, high nutrient concentrations can trigger algal blooms. While some of the algae that form blooms are part of the natural ecology of the State’s waterways, elevated nutrient levels can result in abnormally high concentrations of algal cells and increase the number of toxic and nuisance algal species forming blooms. This can lead to closure of the water body to primary and secondary recreational contact.

Passive treatment systems such as constructed wetlands can improve water quality by acting as preliminary filters, stripping the water of suspended sediments, dissolved nutrients, gross pollutants and
other micropollutants before the water is released into natural wetlands, drainage lines, rivers and/ or streams. Appropriately designed constructed wetlands which mimic the ephemeral character of our natural wetlands are effective water pollution filters as instream and fringing aquatic vegetation provide an ideal structure for the growth of biofilm which assimilates dissolved nutrients. These wetlands can also provide flora and fauna habitat in areas where many natural ephemeral wetlands have been filled or removed and can be incorporated into restoration plans for natural drainage lines or natural wetlands.

Benefits of biofilms

Biofilms are a matrix of bacteria, fungi and algae, often in a polysaccharide film. Biofilms aid in nutrient transformation and reduction by acting as absorption sites. Biofilm growth can be limited by lack of light in highly coloured water which is common on the Swan Coastal Plain due to natural tannins, yet stormwater runoff from urban development is typically less coloured promoting greater light penetration.

Constructed wetlands are one of many features of WSUD that can be built or modified to serve as treatment zones to reduce the flow of nutrients into our rivers and natural wetlands. When designing a constructed wetland, designers should be aware of other WSUD best management practices, such as infiltration basins, vegetated swales, pollution reduction practices (non-structural controls) and gross pollutants traps, which can play a vital role in nutrient reduction and water pollution control. Constructed wetlands can be used downstream of other WSUD best management practices, to form a ‘treatment train’ approach, which treats the water in the catchment as it flows through to the receiving water body. Treating nutrients and pollutants at source, in the catchment itself, is the preferred option for nutrient and other pollutant reduction. A treatment train is often more cost effective than a single constructed wetland as an end of catchment solution.

Design principles for constructed wetlands

For wetlands to be a successful part of a treatment train on the Swan Coastal Plain they need to be specifically designed for local conditions. This section discusses the principles, objectives and general design features necessary to create functional constructed wetlands. These best practice principles are:

Integrate the wetland with local conditions and design for the inputs

It is good practice for the wetland design to take into account the local conditions, such as soils, hydrology (including groundwater), natural surface contours, existing vegetation and drainage lines. The utilisation of the existing contours can reduce potentially expensive construction costs involved with earthworks.

1 Natural drainage lines are important features that should be conserved within any development area. Retention and restoration of these areas are a fundamental component of long-term sustainability and it is the first principle of the Department of Water’s position on stormwater management.
It is essential that the water quality of the inflow is known as this affects the sizing of the wetland and influences the design. Different processes are required to treat different nutrients or pollutants and their components. Inflows with a high amount of sediment or nutrients attached to sediment can be removed by large or deep wetlands that have a high hydraulic retention time (HRT). Dissolved nutrients require different design features, such as alternating bed depths, which create shallow and deep zones and provide areas suitable for biofilm growth. The wetland should be designed so that the uptake capacity equals that of the inputs to the wetland. The hydrological cycle of the wetland has a significant impact on its ability to assimilate nutrients. It is important to know summer and winter flows, when the nutrients (or pollutants) are delivered and their concentrations. If the flows and water quality upstream from the wetland are not yet known, the hydrological effectiveness can be used as the basis for the design.

The Department of Water (DoW) can give advice on water sampling to determine the inflow water quality. The section Recommended water quality sampling summarises the basics of sampling.

Correctly size the wetland

Wetlands need to be sized correctly if they are to treat the volumes of water entering them with some determined degree of efficiency. The channel area required to treat summer baseflows can be much smaller than the floodplain or winter area. Over-sized channels, basins and floodplains can create stagnant pools in summer, which may promote mosquito breeding. Care must be taken to reduce this risk. The hydroperiod (time of water inundation) should determine the depth of the channels and basins, the heights of floodplains, ponds and channel edges and the vegetation layout.

Ensure flow velocities remain low

High flows entering a constructed wetland can scour out the bottom sediments. This can result in the resuspension of accumulated sediment, which in addition to releasing nutrients back into the water can send a sediment plume downstream. This may clog water pipes and drainage channels and adversely impact receiving waters. High flows can also damage instream vegetation and associated biofilms. Ideally the system should have a deeper inlet or flow control system to attenuate high flows. It may be necessary to construct a high flow bypass to protect the wetland from high velocities. In this case the inlet should be designed to convey base flow, normal storm and first flush events into the wetland for treatment but provide the capacity to divert potentially damaging above-design stormwater inflows into a bypass system. See Chapter 9 of the Department of Water’s Stormwater Management Manual for Western Australia (2004–7) for further information.

Incorporate deep inlet zones

Large volumes of sediment can impede the function of the wetland by reducing the wetland depth, clogging vegetation stands and can add to maintenance by clogging pipes. A deep inlet zone can avoid this problem. This zone will capture the larger particles and they will settle to the bottom of the inlet zone. Access to this zone for maintenance needs to be considered.

Design wetland bathymetry and vegetation layout for variations in hydrology, including promoting shallow water areas, and wetting and drying cycles

Alternating deep and shallow zones in the wetland, perpendicular to the water flow, can promote removal of nutrients and contaminants such as nitrogen. Shallow and ephemeral zones are generally well oxygenated promoting mineralisation (transformation of organic nitrogen to ammonium) and nitrification (transformation of ammonium to nitrate). The deeper zones promote denitrification, a process occurring in the absence of oxygen, converting nitrate to gaseous nitrogen, which is then released to the atmosphere (see Wetland water quality processes). Varying depths also provide different habitat zones for both plants and animals, improving biodiversity and system functions.

Incorporating seasonally dry zones in the design of the constructed wetland will promote the aeration of the sediments and limit mosquito breeding by interrupting the breeding cycle.

Create gentle sloping shorelines

Sudden inclines can become public safety hazards, particularly for children, so unless the wetland is going to be fenced off, gentle slopes will limit the risk of accidents and ensure greater public safety. Sloping shorelines create wider ranges of zones for plant growth however, very low slopes can inhibit drainage creating isolated stagnant pools and mosquito breeding areas. Banks should therefore be designed with slopes of 1:6 to 1:8.

Maximise vegetation-water contact by creating dense vegetation stands in the wetland

Although open water is aesthetically pleasing, as an isolated wetland component it provides only limited water quality improvement benefits. Wetland vegetation can aid water treatment by slowing the
flow of the water, promoting sedimentation. Plant parts can filter the water through their stems allowing suspended particles to adhere to the plant stems and foliage. The stems and leaves also provide a good substrate for biofilm growth, which assists in the assimilation of dissolved nutrients. While in the growth phase wetland vegetation can also uptake dissolved nutrients. Many water plants transfer oxygen to their root zone creating aerobic zones conducive to the decomposition of organic material, nitrogen transformations, and discouraging phosphorus release from the sediment (see *Wetland water quality processes*). Instream plants also assist in nutrient reduction by reducing wind turbulence (and particle resuspension) and stabilising soils. Wetlands should therefore be designed to incorporate large sections of dense vegetation. This can be achieved by designing wetlands with densely vegetated treatment channels, this includes the low-flow channel and the high-flow floodplain area, if utilised.

Aquatic *macrophytes* can either be free-floating, submerged or emergent. It is recommended that specialist advice be sought to assist with selecting the most suitable instream species. Care must also be taken to ensure that the design of the vegetation layout maximises interception of stormwater by planting stands perpendicular to water flow, as this will minimise short-circuiting (Figure 1).

**Vegetate around the wetland’s edge**

Fringing vegetation serves as a buffer zone for the wetland, capturing nutrients and pollutants in overland flow and groundwater seepage and filtering them prior to entering into the wetland. Fringing vegetation results in shade that limits weed and algae growth and provides water temperatures more conducive to the processing of nutrients. These areas can also minimise localised erosion during storm events; can act as fauna habitat; promote area aesthetics; and reduce the wind-assisted dispersal of

---

*Figure 1: Vegetation correctly planted perpendicular to flow path compared with vegetation incorrectly planted parallel to flow path*

*Figure 2: Densely vegetated zone in the Liege Street constructed wetland*
midges toward lighting by forming a physical barrier between surrounding residences and the wetland.

**Limit the use of lawn and avoid using fertilisers and pesticides**

It is essential that landscaped wetlands are not surrounded by highly fertilised lawns grown to the water’s edge. Fertiliser use may result in the direct application of nutrients to the wetland by either being washed directly into the wetland from lawn surface runoff or by being inadvertently applied in the wetland, potentially exacerbating nutrient problems. Other lawn maintenance requirements such as mowing can result in grass clippings entering the wetland, which subsequently decay adding further nutrients to the system. Native plants are a cost-effective, aesthetically pleasing and sustainable alternative to lawn around the perimeter of the wetland. Most native plants require no fertiliser, little watering (except in initial establishment phases) and will provide habitat for native fauna. If lawn is an essential feature of the surrounds of the wetland it is recommended that a Nutrient Management Plan be written. The Department of Water can give assistance on how to develop a plan.

It is important to limit herbicide use in wetlands and waterways. See Water Note 22 Herbicide Use in Wetlands which outlines acceptable herbicide use near waterways and wetlands.

**Design as part of a treatment train and use of source controls**

Constructed wetlands should form part of a treatment train for water quality improvement. The efficiency of the constructed wetland to remove all water pollutants will largely be determined by the quality of the water entering the system. Gross pollutants such as street rubbish, lawn clippings and deciduous leaves will reduce the effectiveness of the wetland to remove target pollutants and will reduce the aesthetics of the wetland. Similarly, large amounts of heavy metals and other chemicals can impact on the growth of wetland plants and their associated biofilms. A treatment train design, incorporating pre-treatment systems, such as vegetated swales and/or gross pollutant traps (GPTs), will reduce these loads to the constructed wetland, resulting in a far more efficient water treatment system. These structural systems should be complemented by non-structural pollutant source control through community and industry education and altering maintenance practices. See Chapters 7 and 8 of the Department of Water’s Stormwater Management Manual for Western Australia (2004–7) for further information.

**Design to minimise mosquito and midge risk**

Poorly designed constructed wetlands have the potential to produce significant populations of mosquitoes and chironomid midges, with subsequent impacts on surrounding residents. Therefore, where possible, the water body characteristics with a lower risk rating detailed in the Chironomid Midge and Mosquito Risk Assessment Guide for Constructed Water Bodies (Midge Research Group of Western Australia, 2006) should be incorporated. Some of these lower risk design features include seasonal drying out of the wetland, buffer zones, construction of smooth edges to prevent formation of stagnant, shallow pools and alignment of the long axis of the wetland parallel to the prevailing wind direction.

**What is the design process?**

**Decide on the objectives**

Before starting site investigations or the design process, the objectives for the constructed wetland must be considered. Objectives can include environmental benefits (water quality improvements, hydrological modification, erosion control), habitat value (biodiversity and conservation) or anthropocentric benefits (aesthetics, recreation). Water quality improvement is the primary objective of many constructed wetlands, but a good design can also include secondary objectives such as providing social amenity. Stakeholders need to be aware that including habitat components (e.g. the introduction and encouragement of bird nesting and feeding sites) may add to water quality problems by introducing extra nutrients and may cause potential plant damage.

**Site selection**

The objectives and priorities of the project may depend on the siting of the wetland, namely whether it is a greenfield or retrofit site. Next to vegetation, a significant cost of constructed wetlands is earthworks, so siting and constructing the wetland in conjunction with the construction of a new development or redevelopment may result in overall savings.

**Identify stakeholders**

At an early stage of the project all interested and potentially affected key stakeholders, such as the local government authority, relevant State government departments, Indigenous groups, catchment and community groups should be identified and made aware of the project. The identification of stakeholders and development of a communication plan can assist with the approvals process. Long-term ownership, community
engagement and maintenance responsibilities of the wetland need to be considered and determined at this stage.

**Site investigations**

**Topography**

The site topography will guide design as major changes to the existing topography can significantly increase earthmoving costs. Preliminary information on the site topography can be extrapolated from aerial photographs and existing topography maps. However, before designs can be produced a detailed topographical and feature survey is required at intervals of 0.1 m to 0.2 m. Surveys of the site should include cadastral information such as site boundaries, roads, fences, buildings, existing drainage channels, any other relevant site features including significant trees, vegetation and services, for example gas lines, sewerage pipes and telephone lines. The survey needs to highlight any constraints that may impact on the wetland design and is also useful for development of a demolition/salvage plan for the site.

**Groundwater**

If shallow groundwater is present, regular monitoring of shallow groundwater bores (less than 5 m below the ground surface) will give a good indication of groundwater levels and quality. Bore installation must consider total depth of bore and screening intervals and care must be taken to avoid cross contamination when sampling. See the Department of Water’s Water Quality Protection Note 30 *Groundwater Monitoring Bores* for more information on bore installation.

The bores should be monitored at least quarterly for physical parameters (dissolved oxygen, redox potential, conductivity, pH and temperature), nutrients and groundwater elevation for at least one year. Groundwater sampling, sample handling and analysis are detailed in the Standards Australia and Standards New Zealand’s *Water quality – Sampling Part 11: Guidance on sampling of groundwater* (AS/NZS 5667.11:1998). This will help to establish watertable fluctuations and seasonal changes in groundwater quality. Groundwater elevation data can then be collated to determine groundwater contours across the site and general groundwater flow direction, which may not follow topography. Analysis of groundwater quality

---

**What NOT to do…**

- Exotic plants
- Lack of fringing and instream vegetation
- Short-circuiting
- Fertilised lawn to waters edge
- Unshaded

**What to do…**

- Well-planted native vegetation
- Openings
- Water hyacinth
- Healthy riparian vegetation
will identify any hot spots caused by a contaminated groundwater plume or historical landuse activities such as intensive agriculture, failed septic systems or inappropriate industrial operations.

**Geotechnical survey**

Drilling of bores can provide further information of various soil horizons. Physical properties of the soils should be screened for their suitability as top soil materials because this will influence the success of plant establishment. Clays and other dense soils generally limit root penetration, while coarse, sandy soils have high hydraulic conductivities and typically a low potential for nutrient retention. For optimum plant growth, the top soil should be loamy with medium organic content and should have a depth of ~200 mm. Care should be taken during the construction phase to ensure compaction of the top soil does not occur.

**Acid sulfate soils**

The likelihood of acid sulfate soils (ASS) disturbance needs to be established at the onset of the project to determine whether the site is in an area of acid sulfate soil risk. In the event that ASS disturbance is considered acceptable, it is generally expected that an Acid Sulfate Soil Management Plan will be prepared and implemented. Works should be carried out in a manner that will ensure there is no resultant acid water discharge that may adversely affect the biophysical environment, human health and amenity. Draft guidance on the acid sulfate soil investigation, management and planning are available on the Department of Environment and Conservation’s website at <http://acidsulfatesoils.environment.wa.gov.au>.

**Surface water hydrology and water quality**

If existing surface flows are to enter the wetland, then a monitoring program which measures these flows and their water quality must be undertaken. Water samples should be analysed for nutrients, total suspended solids, electrical conductivity, pH, dissolved oxygen and possibly metals, faecal coliforms, hydrocarbons and biochemical oxygen demand, depending on the source of the water and aims of the wetland. See Recommended water quality sampling.

**Vegetation survey**

Identify existing vegetation communities on-site and in similar wetland types in the region surrounding the wetland site and use these wetland assemblages and systems when designing the wetland. It is recommended that good quality native vegetation be retained and incorporated in the design of the wetland and landscaping.

**Sources of information**

The following table is a summary of helpful information sources to expedite design planning and determine objectives for a constructed wetland.

Table 1: Sources of information

<table>
<thead>
<tr>
<th>Source</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Department of Environment and Conservation</td>
<td>¬ advice on dieback areas ¬ known declared rare or threatened flora/fauna ¬ Bush Forever areas, Wetlands classification mapping ¬ Acid Sulfate Soils Guideline Series</td>
</tr>
<tr>
<td>Swan River Trust</td>
<td>¬ advice on planning</td>
</tr>
<tr>
<td>Landgate</td>
<td>¬ records on landuse, topography information, changing vegetation coverage, aerial photographs, topographical maps and cadastral information</td>
</tr>
<tr>
<td>Bureau of Meteorology</td>
<td>¬ climatic data including rainfall and evaporation</td>
</tr>
<tr>
<td>Department for Planning and Infrastructure</td>
<td>¬ existing and proposed landuse</td>
</tr>
<tr>
<td>Local government authorities</td>
<td>¬ local historic, current and proposed landuse practice ¬ information on site constraints, environmental health issues (such as mosquitoes), accessibility and land ownership</td>
</tr>
<tr>
<td>Department of Indigenous Affairs</td>
<td>¬ Aboriginal sites of archaeological or anthropological significance</td>
</tr>
<tr>
<td>Research centres, libraries, catchment groups, other local environmental groups, adjacent landholders, general community</td>
<td>¬ local landuse practice changes ¬ biological information ¬ historic site information</td>
</tr>
</tbody>
</table>
Identify constraints

The design of the wetland must take into consideration possible constraints. For many Swan Coastal Plain situations these include:

- land availability, including future land use plans;
- types and form of pollutants – e.g. dissolved nutrients, gross pollutants, toxicants, sediment;
- delivery of pollutants – e.g. mostly diffuse, including when pollutants arrive (need to consider baseflows and first flush events);
geology – e.g. very sandy soils, bedrock;
hydrology – e.g. often high groundwater table;
topography – e.g. very flat or steep site;
site specific constraints – e.g. environmental, conservation and heritage issues;
end use of the treated water – e.g. delivery into downstream waterways, reuse as irrigation water;
location of services;
other end uses of site – e.g. active/passive recreation; and/or
hydraulics including levels of existing pipework and flows.

Seek approvals
Consultation needs to be undertaken with the relevant government authorities. Proponents must check cultural and heritage values including Aboriginal heritage; impacts on flora and fauna; bioaccumulation of metals and other contaminants; pests; weeds; fish passage; erosion control; groundwater protection; and a range of impacts on the community including public health and safety such as vector control.

Development of design
Using the information from the site investigations, together with an appreciation of the constraints, a conceptual design can be developed. This stage may indicate that information gaps are present highlighting the need for further site investigations or stakeholder consultation. It is useful at the conceptual stage to develop a schedule of costs for design and construction to ensure the funding agencies are aware of their financial responsibilities. Once the design has been endorsed by the stakeholders the proponents can move towards seeking approvals and developing the final design.

Wetland components – how it comes together

Inlet
The flow velocities in the wetland need to be managed by careful consideration of stage levels and flows when designing the geometry. A deep inlet or similar system should be used to attenuate high flows. A diversion structure may be required to ensure that potentially damaging above-design high flows bypass the wetland. It is important that this structure is designed to allow normal storms and first flush events to enter the wetland for treatment.

Detailed hydraulic modelling should be undertaken to determine design flows for the wetland.

Low flow areas – channels/creeklines and basins
Creeklines (channels) and basins form the main treatment area for low flows. Channel widths should vary in an effort to move away from a linear type drainage line. Shallow, wide, meandering streams with a series of deeper basins are often very effective in constructed wetlands as they increase detention times and create a more diverse range of habitats, which can promote nutrient removal processes. Average channel cross sectional areas should provide sufficient volume to account for increases in hydraulic roughness or surface friction established by instream vegetation.

Channels and basins may need to be lined with a less permeable layer (e.g. clay) to reduce groundwater interactions. The invert or bottom of the channel or basin should be above maximum groundwater levels, however, capillary action will allow soils to stay wet almost all year in shallow groundwater areas and maintain vegetation.

Channels can incorporate:

- **Open water basin areas** – should be deeper than 1 m and are best located in flat areas of the wetland.
- **Vegetated sections** – about 70% of total channel area should be vegetated in stream (i.e. less than 30% open water), fully intercepting flows to maximise settling, biofilm and plant uptake and microbial assisted nutrient transformations.
- **Riffles** (rocks placed instream) – can be constructed in sections of the channel that are steeper to reduce the risk of erosion. Riffles promote oxygenation of water (necessary in the breakdown of ammonium) and create additional macroinvertebrate habitat such as habitat for filter feeders.

High flow areas – floodplain
The floodplain area attenuates higher flows. Depending on the type of *in situ* soils, the area may require lining. **Swales** and floodplains treat both overflow from baseflow channels and rising groundwater. The floodplain slope and/or soil permeability should allow for water inundating the floodplain area to either infiltrate into the groundwater or flow back into the channel as flows recede. To reduce the risk of mosquito breeding there should be no surface water within floodplain areas within four days of being inundated (within high risk areas or mosquito breeding risk times of the year).
Table 2: Stormwater treatment components of a constructed wetland

<table>
<thead>
<tr>
<th>Zone</th>
<th>Functions</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet</td>
<td> buffer wetland from high flows</td>
<td> piped inlets</td>
</tr>
<tr>
<td></td>
<td> sedimentation</td>
<td> diversion into wetland</td>
</tr>
<tr>
<td></td>
<td> gross pollutant removal</td>
<td> bubble up pit</td>
</tr>
<tr>
<td>Channel</td>
<td> filtration and sedimentation</td>
<td> &gt;100 mm clay layer</td>
</tr>
<tr>
<td></td>
<td> evenly distribute flow and reduce flow velocity to promote further</td>
<td> 200 mm topsoil over clay layer</td>
</tr>
<tr>
<td></td>
<td>filtration and sedimentation</td>
<td> gently sloping embankments to reduce erosion</td>
</tr>
<tr>
<td></td>
<td> biological transformations and uptake</td>
<td> emergent plants with extensive shallow roots in low flow section planted</td>
</tr>
<tr>
<td></td>
<td> habitat for invertebrates</td>
<td>perpendicular to flow path</td>
</tr>
<tr>
<td></td>
<td></td>
<td> riffles in high flow/steep sections</td>
</tr>
<tr>
<td>Open water basin</td>
<td> aeration</td>
<td> &gt;100 mm clay layer</td>
</tr>
<tr>
<td></td>
<td> additional detention volume</td>
<td> 200 mm topsoil</td>
</tr>
<tr>
<td></td>
<td> pollutant transformation</td>
<td> gently sloped embankments</td>
</tr>
<tr>
<td></td>
<td> biofilm growth</td>
<td> offset inputs and outputs of flow path to avoid short-circuiting and</td>
</tr>
<tr>
<td></td>
<td> reduction of flow velocity</td>
<td>increase HRT</td>
</tr>
<tr>
<td></td>
<td> treatment of localised groundwater if groundwater interception occurs,</td>
<td> various depths between and within basins to create habitat</td>
</tr>
<tr>
<td></td>
<td>however constructed wetlands at new sites should not artificially</td>
<td></td>
</tr>
<tr>
<td></td>
<td>expose groundwater</td>
<td></td>
</tr>
<tr>
<td></td>
<td> habitat and refuge for fauna, especially invertebrates</td>
<td></td>
</tr>
<tr>
<td></td>
<td> diverse habitat for flora</td>
<td></td>
</tr>
<tr>
<td>Swale / floodplain</td>
<td> detention of winter flows</td>
<td> &gt;100 mm clay-sand layer</td>
</tr>
<tr>
<td></td>
<td> optimisation of water treatment using dense vegetation with dense</td>
<td> 200 mm topsoil</td>
</tr>
<tr>
<td></td>
<td>shallow root system for biofilm creation</td>
<td> dense vegetation cover to encourage sedimentation and reduce erosion</td>
</tr>
<tr>
<td></td>
<td> increase in permeability and infiltration to groundwater, adsorption</td>
<td> gentle swale gradients to reduce scoring and increase vegetation</td>
</tr>
<tr>
<td></td>
<td>and sedimentation through use of clay-sand semi-permeable topsoil</td>
<td>diversity</td>
</tr>
<tr>
<td></td>
<td>cover and dense vegetation</td>
<td></td>
</tr>
<tr>
<td></td>
<td> promotion of biofilm growth for bacterial transformations</td>
<td></td>
</tr>
<tr>
<td></td>
<td> habitat creation for bacteria, fungi and fauna</td>
<td></td>
</tr>
<tr>
<td>Outlet</td>
<td> controls stormwater detention time</td>
<td> riser pit or V-notched weir</td>
</tr>
<tr>
<td></td>
<td> can allow for effective gauging</td>
<td></td>
</tr>
</tbody>
</table>

Vegetation design

Remnant vegetation areas should be retained and/or restored in keeping with the objectives of the constructed wetland. Choice of vegetation species for each zone depends on the expected hydroperiod and the substrate. In accordance with the Department of Water and Swan River Trust (2005) Decision Process for Stormwater Management in WA, constructed wetlands should not artificially expose groundwater. If necessary, ephemeral plants should be chosen in preference to species that require permanent inundation. Plant structures should be fairly open allowing passage of water, sunlight penetration and optimum biofilm growth, yet have dense surface roots.

Planting densities depend on lead time before stormwater enters the system, planting season and weed risk, however, a general density of four plants/m² is recommended for channel and basin areas. Planting densities need to be high to reduce weed competition and minimise ongoing maintenance costs. Planting densities can be lower for floodplain areas where an average three plants/m² is recommended. Plants should be planted in rows perpendicular to the flow path with each row offset from the previous to minimise short-circuiting and the creation of preferential flow paths (see Figure 1).

The ideal time to plant low flow channel and basin areas is in early to mid-spring when plant growth is at its optimum. Floodplain areas should be planted in winter unless the area will be irrigated.

The success of planting is critical to the establishment phase. Water levels may need to be manipulated to ensure that soils are saturated for at least eight weeks after planting or until seedlings exceed 200 mm in height. To avoid loss of vegetation it is also important that water levels do not exceed two thirds of the lowest species’ height. It is critical to allow time for plants to establish themselves before the wetland becomes fully operational.
### Table 3: Vegetation types

<table>
<thead>
<tr>
<th>Vegetation zone</th>
<th>Vegetation types</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>channel and shallow basins</td>
<td>closed sedgeland and rushes</td>
<td><em>Eleocharis acuta, Baumea juncea, B. articulata, Juncus kraussii</em></td>
</tr>
<tr>
<td>near-permanent basins</td>
<td>scattered sedgeland with submergents</td>
<td><em>Triglochin huegelii, Villarsia spp, Schoenoplectus validus</em></td>
</tr>
<tr>
<td>lower swale/floodplain</td>
<td>melaleuca woodlands</td>
<td><em>Melaleuca rhaphiophylla, M. preissiana</em></td>
</tr>
<tr>
<td>upper swale (dryland)</td>
<td>closed rushland, sedgeland and heathland</td>
<td><em>M. preissiana, Kunzea ericifolia, Baumea juncea</em></td>
</tr>
</tbody>
</table>

### Maintenance and monitoring

Maintenance issues, such as plant replacement, weed control, mosquito and midge control, and sediment removal need to be considered in terms of timelines and responsibilities, and be incorporated into a management plan. Weed management is important. Site preparation involving weed eradication followed by a targeted weed management program is essential.

If a constructed wetland scores a ‘low risk’ according to the *Chironomid Midge and Mosquito Risk Assessment Guide for Constructed Water Bodies* (Midge Research Group of Western Australia, 2006), then it is likely that minimal monitoring and maintenance for chironomid midges and mosquitoes would be required. The majority of the constructed wetland design features outlined in this *River Science* edition are considered lower risk, such as seasonal drying out, fringing (buffer) vegetation and prevention of shallow, stagnant pools. For constructed wetlands or zones such as densely vegetated, shallow channels, which would be considered higher risk, regular monitoring, including larval and adult trapping should be undertaken to determine if further control/treatment options are necessary.

To determine whether the wetland is performing as expected, a monitoring program detailing hydrology and the water quality of inflow and outflow is...
recommended. At a minimum, the following monitoring should be undertaken:

- monitoring of surface water levels and flow pathways and groundwater levels in the wetland is necessary to ascertain whether the actual wetland hydrology matches that of the design intent; and
- monitoring of the inflow and outflows for total suspended solids, and nutrients should be undertaken in low flow and high flow periods.

**Wetland water quality processes**

To improve water quality it helps to understand nutrient processes and how they occur in wetlands. Further information on the overall cycling of nitrogen and phosphorus in the environment is detailed in *River Science 4 Nitrogen and Phosphorus cycles*.

**N – nitrogen**

Nitrogen can be removed via nitrogen transformations (mineralisation, nitrification, and denitrification); physical processes (sedimentation); biological processes (plant and microbial uptake); and ammonia volatilisation.

**P – phosphorus**

Phosphorus can be removed via adsorption; physical processes (sedimentation and filtration); and biological processes (plant and microbial uptake).
A repeated wetting and drying process in wetlands is natural and beneficial. It assists in the breakdown of organic matter, denitrification, and in the reduction of phosphorus by allowing conversion of sediment iron oxides and adsorbed phosphorus to less available forms.

Other pollutants
Suspended material can be removed from the water column by sedimentation and filtration. Organic matter can be removed through sedimentation/filtration, degradation and microbial uptake. Pathogens can be destroyed by exposure to ultraviolet light in open waters, adsorption and predation. Some heavy metals can be removed through sedimentation, adsorption and plant uptake, although high levels of metals can be toxic to plants and animals and may have significant adverse impacts on a wetland.

Recommended water quality sampling
Before designing and constructing a wetland it is recommended that surface and groundwater samples be taken for laboratory analysis to accurately determine the existing water quality. Parameters analysed should include nutrients (total and dissolved nitrogen and phosphorus), physical-chemical parameters (e.g. pH, dissolved oxygen, conductivity and temperature) and total suspended solids. Concentrations of dissolved organic carbon, biochemical oxygen demand and total heavy metals may also be useful to know. Surface water collection methods, sample handling and analysis is detailed in the Standards Australia and Standards New Zealand’s Water quality – Sampling. Part 1: Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples (AS/NZS 5667.1:1998).

In addition to sampling, noting the condition of the water is an easy and quick preliminary method to visually assess the water quality. For example, high dissolved organic carbon content is often indicated by dark coloured water. Murky or muddy water is an immediate indication of high suspended solids. Observations of erosion in the surrounding environment can indicate that suspended solids may be high. An assessment of the surrounding landuse allows for some degree of speculation of the condition of the water but thorough water quality sampling is needed before any final design can be undertaken.

Constructed wetlands in action
The Swan River Trust’s Drainage Nutrient Intervention Program (DNIP) implements on-ground works to improve water quality in the Swan and Canning rivers. The first initiative of this program was the construction of the Liege Street Wetland which aims to improve stormwater quality before discharge into the Canning River upstream of the Kent Street Weir. The site at Carden Drive, Cannington was identified for potential nutrient stripping works in early August 2003 initiating stakeholder consultation and a design workshop in early November 2003. Refinement of design continued until wetland construction works began in early April 2004. Planting of the wetland commenced in June 2004 and continued through to 2006. Post-works monitoring commenced in late 2004. For more information on the Liege Street constructed wetland see the Swan River Trust’s website <www.swanrivertrust.wa.gov.au>.

For further information on planned and existing constructed wetlands refer to Chapters 6 and 9 of the Stormwater Management Manual for Western Australia (Department of Water 2004–7).

Glossary
Adsorption – the binding of compounds to a surface in a readily exchangeable form, such as nutrients to another compound, such as a sediment grain.
Aerobic – with oxygen, usually referring to chemical reactions or organisms.
Anaerobic – without oxygen, usually referring to chemical reactions or organisms.
Bathymetry – the measurement of water depth to determine the underwater topography.
Biochemical Oxygen Demand (BOD) – measure of the oxygen consumption by microbiological breakdown of organic matter such as plant debris, faeces and other wastes, typically measured over a five-day period. Waters with high BOD contribute to a high oxygen demand in the receiving aquatic environment, reducing the amount available for use by aquatic organisms.
Biofilm – a gelatinous matrix of bacteria, algae and fungi.
Ephemeral – periodically drying; only remaining wet for part of the year.
Epiphyte – Any living organism, plant, animal, bacteria, fungi growing on a plant.
Greenfield – a site where there is no existing development (cf retrofit).

HRT – hydraulic retention time; amount of time a water parcel is in the wetland.

Hydraulic efficiency – extent of wetland volume utilised in flow movement, and extent of plug flows.

Hydraulic roughness – bed roughness creating friction which retards the flow of water.

Hydrologic regime – long-term spatial variation in depth and period of inundation.

Hydrological effectiveness – interaction between the runoff capture, hydraulic retention time (HRT) and volume of wetland; the proportion of stormwater volume that enters the wetland under the prescribed HRT.

Macrophyte – a plant that is visible with the naked eye.

Mineralisation – the process of breaking down of complex organic molecules into simple inorganic molecules, often mediated by bacteria.

Retrofit – to integrate (either new or by modifying) a treatment system in an existing development (cf greenfield).

Short-circuiting – where the inflow can bypass much of the treatment volume, limiting water quality treatment.

Swale – shallow vegetated depression that conveys water during high rainfall.
Acknowledgments

This River Science series is an initiative of the Water Science Branch of the Department of Water with funding from the Swan River Trust’s Swan-Canning Cleanup Program. This issue was written by Rachel Spencer and Naomi Hellriegel. Thanks go to Tom Rose for editorial comment.

For more information


Swan River Trust
Level 1 Hyatt Centre 20 Terrace Road
East Perth Western Australia 6004
Telephone: (08) 9278 0900
Facsimile: (08) 9325 7149
Website: www.swanrivertrust.wa.gov.au

Tell us what you think of our publications at info@swanrivertrust.wa.gov.au

ISSN 1443-4539
Printed on environmentally friendly paper
September 2007