Chapter 14 **Other measures**

14.1 Introduction

There are a range of 'other' **stormwater** management and treatment measures that can be considered as part of the available toolkit for the WSUD practitioner. These 'other' measures are either proprietary devices or may have a differing scope of application to the more mainstream techniques discussed earlier in this Manual and, as such, no detailed design procedures have been prepared for them. The following sections of this chapter provide general guidance on the characteristics of these additional techniques for review and further consideration by interested designers of a WSUD-oriented project.

The techniques that are discussed include the following:

- subsurface **wetlands**
- proprietary products
- porous pavements
- use of natural areas including reforestation and revegetation.

14.2 Subsurface wetlands

Figure 14.1 provides an example of indicative cross-sections of both free surface and subsurface wetlands (source Queensland Department of Natural Resources and Mines (DNRM) 2000). The 'free surface' wetland illustrated in Figure 9.1 is addressed in Chapter 9 of this Manual. The discussion here relates to the subsurface flow wetland in which the flow to be treated passes through a porous media such as sand or gravel which underlies the wetland.

Subsurface wetlands are typically applied in a wastewater treatment system where there is a relatively consistent influent flow rate. To date in Australia, there have been few, if any, applications of these techniques in the stormwater field, though there are obvious overlaps between a porous media, a planted bioretention system and a vertical subsurface flow wetland.

One of the major issues associated with the use of subsurface flow wetlands in a stormwater treatment context relates to the highly episodic nature of stormwater events. A subsurface wetland would require considerable volumes of balancing/detention storage above it to attenuate stormwater inflows. There may also be problems with the subsurface wetlands excessively drying under prolonged low rainfall conditions with associated losses of algal and microbial slime layers.

The following general guidance on subsurface flow wetlands has been broadly sourced from DNRM (2000).

- Subsurface wetlands, commonly referred to as reed beds, consist of channels or basins that contain gravel or sand media which support emergent type vegetation. The purpose of the vegetation is to provide some oxygen to the root zone.
- The environment with a subsurface wetland is mostly anoxic or anaerobic. Some oxygen is supplied to the roots, which is likely to be used up in the biomass growing there rather than penetrate too far into the water column and, for this reason, subsurface wetlands are effective in denitrification.

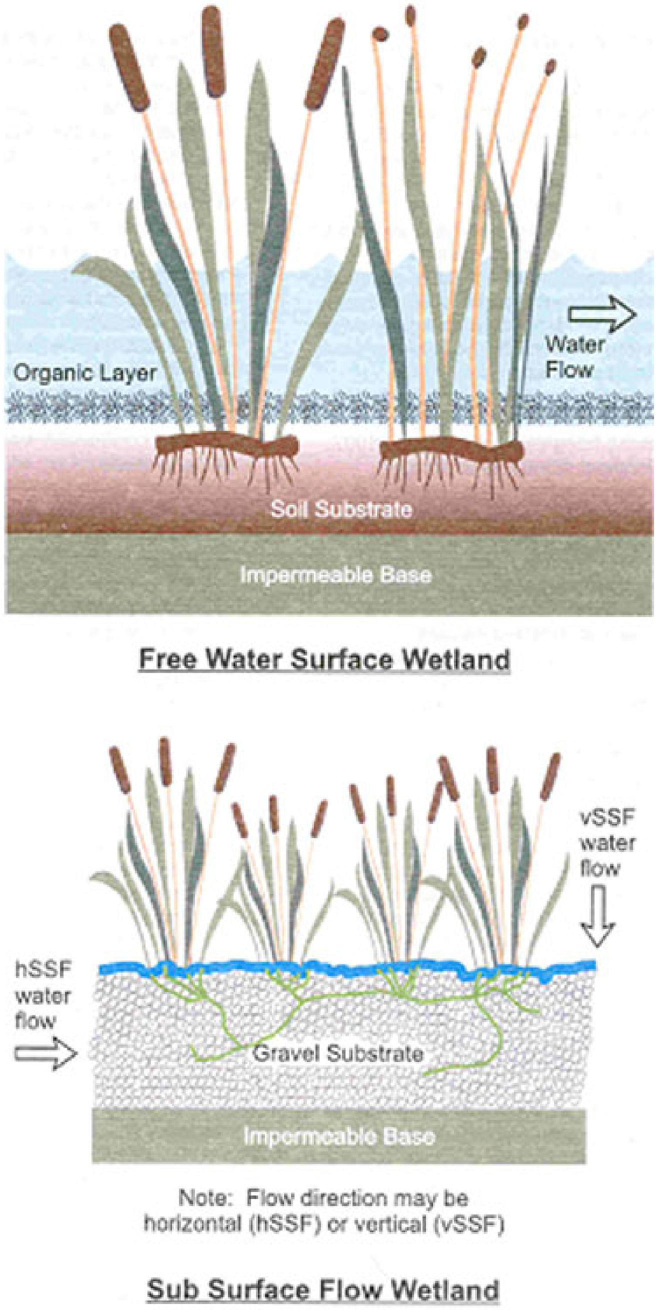

Figure 14.1 Major types of **constructed wetlands** (from Queensland Department of Natural Resources and Mines 2000)

Reported advantages of subsurface wetlands are as follows:

- significant ability to treat high organic loads
- high cold weather tolerance
- greater treatment per unit area when compared to free surface wetlands
- mosquitos and odours are generally not a problem
- there are no public safety issues as the wetland is not a body of open water
- resuspension of sediment (e.g. due to wind, birdlife) is eliminated (unlike surface wetlands)
- horizontal flow paths through porous media require only mild hydraulic gradients (hence long **detention times**)
- there are minimal harvesting needs.

Reported disadvantages of subsurface wetlands are as follows:

- intermittent stormwater flows may adversely affect treatment
- higher capital cost, associated with media supply

Table 14.1 Typical design criteria and expected effluent quality for subsurface wetlands (after Crites and Tchobanoglous 1998)

Item	Value
Detention time	3–4 days
Biological Oxygen Demand (BOD)loading	0.01 kg/m^2 per day
Suspended solids loading[A] (see note)	0.04 kg/m^2 per day
Water depth	up to 0.6 m
Media depth	up to 0.75 m
Harvesting	Limited
Expected effluent quality:	
BOD	< 20 mg/L
Suspended solids	< 20 mg/L
Total nitrogen	< 10 mg/L
Total phosphorus	< 5 mg/L

Note [A]For wetland length to width ratio of greater than 4:1, the influent suspended solids loading may be a concern. To avoid entry zone blockages, suspended solid loadings should not exceed 0.08 kg/m2 per day (Bavor et al. 1989).

- they can be prone to blockage, particularly at the **inlet zones**
- they are limited to smaller pollutant loadings.

A frequently reported problem with subsurface wetlands is blockage of the inlet zones which then leads to short circuiting and surface flow. Attention needs to be given to good inflow distribution and the placement of larger aggregate within this inlet zone. Inlet apertures need to be large enough to avoid being blocked by algal growth and designs should aim to facilitate regular inspections for maintenance purposes.

Primary design criteria for subsurface flow wetlands are:

- detention time
- organic loading rate
- hydraulic loading rate
- media size
- bed depth
- aspect ratio.

Typical design criteria from other countries for wastewater subsurface wetlands are provided in Table 14.1.

14.3 Proprietary stormwater treatment devices

In the development of a WSUD **treatment train** for a site, there is an extensive array of proprietary products available for consideration. Such proprietary products usually take a primary treatment role, removing gross pollutants and litter before other devices (as described in the earlier design procedures in this Manual) address the fine sediment, nutrient and pathogen content of urban stormwater. However, there are also products available for **sedimentation**, spill controls, oil separation and fine filtration.

Given the diversity of forms and configurations of these proprietary devices and, in some cases, the confidential nature of their design and performance data, this Manual provides general guidance as to the issues that should be considered when selecting such devices. We also provide some guidance as to those factors which should be considered when reviewing performance values often ascribed to such devices by suppliers.

14.3.1 Selection issues

Engineers Australia (2003) provide guidance as to those issues which should be considered when selecting a **gross pollutant trap, GPT**. Such devices constitute most proprietary products. The following summary of key selection issues has been developed on the basis of the Engineers Australia (2003) advice.

A decision of which type (and brand) of proprietary device to select is a trade-off between the life cycle costs of the device (i.e. by combining capital and ongoing costs), expected pollutant removal performance in regard to the values of the downstream waterbody and social considerations.

A life cycle cost approach is recommended. This approach allows the ongoing cost of operation to be considered and the benefits of different devices to be assessed over a longer period. The overall cost of a proprietary device is often determined more by the maintenance costs rather than the initial capital costs.

The expected pollutant removal rate is a function of the amount of runoff treated (i.e. the quantity of flow diverted into a proprietary device compared to that which bypasses) and the pollutant removal rate for flows that go through a proprietary device.

This section highlights some issues that should be considered as part of the decision-making process. The issues raised are primarily based on experience with existing proprietary device installations.

14.3.1.1 Life cycle costs

Life cycle costs are a combination of the installation and maintenance costs and provide an indication of the true long-term cost of the infrastructure. It is particularly important to consider life cycle costs for proprietary devices as maintenance costs can be significant compared to the capital costs of installation.

To determine life cycle costs, an estimated duration of the project (i.e. lifespan of the treatment device) needs to be assumed (e.g. 20 or 25 years). If the device is to control pollutants during the development phase only (e.g. a sediment trap) its life cycle may be only three to ten years.

Life cycle costs can be estimated for all devices and then, with consideration to the other influences (e.g. expected pollutant removal, social), the most appropriate device can be selected.

14.3.1.2 Installation costs and considerations

Installation costs include the cost of supply and installation of a proprietary device. These prices should be evident on proposals for proprietary device installations but it should be checked that all installation costs are included. Variables in terms of ground conditions (e.g. rock or groundwater conditions) or access issues may vary construction costs significantly and cost implications of these should be assessed. The likely occurrence of these issues should be weighed up when estimating an overall installation cost.

Issues that should be checked as being addressed by tenderers include:

- price includes supply and installation (not just supply)
- provision for rock or difficult ground conditions
- proximity to services (and relocation costs)
- required access and traffic management systems for construction.

A true installation cost should then be used when estimating life cycle costs.

As important as obtaining a true installation cost is ensuring that the device will suit local conditions. Issues that should be assessed to ensure a proprietary device will suit an area include:

1 the size of the unit
2 hydraulic impedance caused by the device
3 particular construction issues.

Size of the unit (footprint, depth)

The sizes of proprietary devices vary considerably and this will need to be accommodated by the potential location for the device. Things to consider when assessing the size of a device include:

- required footprint (plan size of device and any required flow diversion)
- depth of excavation (to the bottom of the sump in some cases) – rock can substantially increase installation costs
- sump volume required (where applicable)

- proximity to groundwater
- location of any services that affect construction and likely cost for relocation (e.g. power, water sewer).

Hydraulic impedance/requirements

Some proprietary devices require particular hydraulic conditions in order to operate effectively; for example, some devices require a drop in a channel bed for operation. Requirements such as these can affect which devices may or may not be suitable in a particular area.

Other considerations are possible upstream effects on flow and a hydraulic gradeline because of the installation of the device. This can increase flooding risks and all devices should be designed to not increase the flooding risk during high flows. Therefore, if a device increases the flooding risk above acceptable limits, it may not be considered further.

Other construction issues

For each specific location there will be several other considerations and points of clarification that may sway a decision on which device may be the most suitable. These include the following.

- Does the cost include any diversion structures that will be required?
- Is specialist equipment required for installation (e.g. special formwork, cranes or excavators) and what cost implications do these have?
- Is particular below-ground access required, will ventilation and other safety equipment be needed – at what cost?
- Will the device affect the aesthetics of an area – will landscape costs be incurred after the device installation – if so how much?
- Will the device be safe from interloper or misadventure access?
- Do the lids/covers have sufficient loading capability (particularly when located within roads) – what is the cost of any increase in load capacity and will it increase maintenance costs?
- Will the device be decommissioned (e.g. after the development phase) and what will this cost be – what will remain in the drainage system?
- Are there tidal influences on the structure and how will they potentially affect performance or construction techniques?
- Will protection from erosion be required at the outlet of the device (particularly in soft bed channels), and what cost implications are there?

14.3.1.3 Maintenance costs and considerations

Maintenance costs can be more difficult to estimate than the installation costs (but are sometimes the most critical variable). Variation in the techniques used, the amount of material removed and the unknown nature of the pollutants exported from a **catchment** (thus disposal costs) all influence maintenance costs. It is, therefore, imperative to carefully consider the maintenance requirements and estimate costs when selecting a proprietary device. As part of a tender process, tenderers should be asked to quote annual maintenance prices, based on the relevant site conditions (not just generic estimates).

One important step is to check with previous installations by contacting the owners and asking their frequency of cleaning and annual operation costs (vendors can usually supply contact information).

All maintenance activities should be developed that require no manual handling of collected pollutants because of safety concerns with hazardous material.

Below is a list of maintenance considerations that should be applied to all proprietary devices.

- Is special maintenance equipment required (e.g. large cranes, vacuum trucks or truck-mounted cranes)? Does this equipment need to be bought or hired – at what cost?
- Is special inspection equipment needed (e.g. access pits)?
- Are any services required (e.g. washdown water, sewer access)?
- Are there overhead restrictions such as power lines or trees?
- Does the water need to be emptied before the pollutants – if so how will it be done, where will it be put and what will it cost?
- Can the device be isolated for cleaning (especially relevant in tidal areas)?

- Are road closures required and how much disturbance will this cause?
- Are special access routes required for maintenance (e.g. access roads or concrete pads to lift from) – and what are these likely to cost?
- Is there a need for dewatering areas (e.g. for draining sump baskets) and what implications will this have?

Disposal costs

Disposal costs will vary depending on whether the collected material is retained in wet or free draining conditions in the proprietary device. Handling of wet material is more expensive and will require sealed handling vehicles.

- Is the material in a wet or dry condition and what cost implications are there?
- Are there particular hazardous materials that may be collected and will they require special disposal requirements (e.g. contaminated waste –what cost implications are there?
- What is the expected load of material and what are likely disposal costs?

Occupational health and safety

- Is there any manual handling of pollutants and what will safety equipment cost?
- Is entering the device required for maintenance and operating purposes – will this require confined space entry? What cost implications does this have on the maintenance cycle (e.g. minimum of three people on site, safety equipment such as gas detectors, harnesses, ventilation fans and emergency oxygen)?
- Are adequate safety features built into the design (e.g. adequate step irons and inspection ports) or will these be an additional cost?

14.3.1.4 Miscellaneous considerations

Social considerations can be an important component of the selection of a proprietary device. Consultation with key stakeholders is fundamental to selecting an appropriate proprietary device. Influences on the decision process may include:

- potential odour concerns at a location
- likelihood of pests and vermin such as mosquitos or rats
- suitability of the proprietary device materials, particularly in adverse environments (e.g. marine)
- effect on the aesthetics of an area
- education and awareness opportunities
- potential trapping of fauna (e.g. turtles, eels and fish).

These issues should be considered early in the selection process and taken into account when finalising a proprietary device type.

14.3.1.5 Checklist for selecting proprietary products

The following checklist is reproduced from Engineers Australia (2003) and provides guidance on issue to consider when selecting proprietary stormwater treatment products.

1. GENERAL	YES	NO
• Is there available space for the device (i.e. required footprint, access routes, services)?	☐	☐
• Does the location suit catchment treatment objectives (e.g. position in a 'treatment train')?	☐	☐
• Is the pollutant holding chamber suitable (wet or dry retention)?	☐	☐
• Are there sufficient safety precautions (i.e. preventing entry, access for cleaning)?	☐	☐
• Is the visual impact satisfactory (and odour potential)?	☐	☐
• Is the treatment flow sufficient to meet treatment objectives?	☐	☐
• Has the flooding impact being demonstrated to be satisfactory?	☐	☐
• Has sufficient consultation taken place with operation staff and affected locals?	☐	☐
• Is the expected pollutant removal rate sufficient to meet treatment objectives (consult with owners of existing installations if required)?	☐	☐

2. INSTALLATION		
• Does the price include installation?	☐	☐
• Are there sufficient contingencies for ground conditions (e.g. rock, shallow water table, soft soils etc.)?	☐	☐
• Have relocation of services being included?	☐	☐
• Are there sufficient access or traffic management systems proposed as part of construction?	☐	☐
• What are the cost implications of the above points? $______________	☐	☐
3. MAINTENANCE		
• Is the method of cleaning applicable to local conditions (e.g. OH&S issues, isolation of the unit from inflows etc.)?	☐	☐
• Are the maintenance (cleaning) techniques suitable for the responsible organisation (ie. required equipment, space requirements, access, pollutant draining facilities etc.)?	☐	☐
• Is a maintenance contract included in the proposal?	☐	☐
• Is the size of the holding chamber sufficient?	☐	☐
• Have disposals cost being accounted for?	☐	☐
• What are the cost implications of the above points? $______________	☐	☐

14.3.2 Performance issues

When considering the adoption of a proprietary device for a particular site, as well as the selection issues addressed above, it is recommended that consideration be given to how the device will perform, especially in respect to the levels of performance which are often attributed to such devices by their suppliers.

In this regard, it is recommended that consideration be given to the following key issues (Auckland Regional Council 2003).

- Whether the operating parameters of the system have been verified.
- Existing or proposed monitoring data.
- Documentation of processes by which pollutants will be reduced (physical, chemical, biological).
- Documentation and/or discussion of potential causes of poor performance or failure of the device.
- Key design specifications or considerations.
- Specific installation requirements.
- Specific maintenance requirements.
- Data to support claimed pollutant removal efficiencies. If the device is new or the existing data is not considered reliable, such data should be viewed with caution.

14.4 Porous pavements

Fletcher et al. (2003) provides an Australian review of available data on porous pavements, combined with advice on maintenance and operational issues, is contained in the following material has been reproduced from this publication (with the permission of the lead author).

14.4.1 Description

Porous pavements, as their name implies, are a pavement type that promote infiltration, either to the soil below, or to a dedicated water storage reservoir below it. Porous pavements come in several forms (Figure 14.2), and are either monolithic or modular. Monolithic structures include porous concrete and porous pavement (asphalt). Modular structures includes porous pavers (which may be either made of porous material, or constructed so that there is a gap in between each paver), modular lattice structures (made either of concrete or plastic). Porous pavements are usually laid on sand or fine gravel, underlain by a layer of geotextile, with a layer of coarse aggregate below. Design should ensure that the required traffic load can be carried.

Figure 14.2 Examples of porous pavement: porous car park, Washington, DC, USA (Photo: Ecological Engineering); porous car park, road gutter, Manly, NSW (Photo: Tim Fletcher).

An advantage of modular pavers is their ability to be lifted, backwashed and replaced when blockage occurs. Pavers that are porous from the use of gaps between individual pavers should be carefully chosen with reference to likely catchment inputs, such as leaves and debris that can quickly block the gaps.

Porous pavements should generally be located in areas without heavy traffic loads. In high traffic areas the loads of pollutants can significantly decrease the ability to remain porous. Consideration of the maintenance advantages of modular pavers should also be considered, given that the consequence of blockage with monolithic material

Porous pavement has two main advantages over impervious pavement, in terms of stormwater management:

1 improvement to water quality, through filtering, interception and biological treatment
2 flow attenuation, through infiltration and storage.

14.4.2 Studies of performance

Investigations into the performance of porous pavements have investigated (a) water quality and (b) flow effects.

14.4.2.1 Flow behaviour

Porous pavements can potentially reduce peak flow rate, and total flow volume, the individual or combined effect of initial loss, infiltration, storage and evaporation. The level of flow attenuation is dependent in part on (where appropriate) the amount of storage, and the infiltration capacity of the porous pavements, its underlying base material (including any underlying geotextile), and the soil below.

14.4.2.2 Water quality behaviour

Porous pavements act to improve water quality through a number of mechanisms:

- filtering through the pavement media, and underlying material
- potential biological activity within the pavement and base material
- reduction of pollutant loads, as a result of reduced runoff volumes.

Observed behaviour is likely to be a function of the particular storm event (its magnitude and intensity), the input concentration, and the characteristics of the pavement media and underlying filter material.

Importantly, since contaminants such as heavy metals and hydrocarbons are often attached to sediment, the filtering behaviour acts not only to reduce sediment loads, but also those of associated contaminants. Because of the ability of porous pavement to provide an initial rainfall loss, runoff from porous pavement is less likely to have the oft-observed 'first-flush' effect, where greatly elevated pollutant concentrations are observed in the first part of a storm.

Table 14.2 Summary of expected porous pavement performance
(after Fletcher et al. 2003)

Pollutant	Expected concentration reduction (%) (+ range)	Comments
Total Suspended Solids (TSS)	80 (70–100)	
Total Nitrogen (TN)	65 (60–80)	Will decrease with proportion dissolved
Total Phosphorus (TP)	60 (40–80)	Will decrease with proportion dissolved
Hydrocarbons/Oils/Grease	85 (80–99)	Depends on level of microbial activity.
Biological Oxygen Demand (BOD)	–	Inadequate data
Lead, copper, cadmium, zinc and nickel	75 (40–90)	Will decrease with proportion dissolved
Litter	–	Litter will simply 'wash off'
Pathogens	–	Inadequate data

14.4.2.3 Summary of expected performance

Based on the studies of flow performance reviewed by Fletcher et al. (2003), and contingent upon the properties and condition of the porous pavement and its subsoil, a reduction in runoff coefficient from around 0.95 for traditional pavements, to around 0.40 can be expected. However, the expected hydraulic performance of any porous pavement can be easily modelled, either for a single rainfall event (using a spreadsheet approach), or using a rainfall–runoff model, such as that provided in the **Model for Urban Stormwater Improvement Conceptualisation (MUSIC)** (Cooperative Research Centre for Catchment Hydrology 2003), for a real (or synthetic) rainfall series.

Based on the studies of water quality performance reviewed Fletcher et al. (2003), the pollutant removal by porous pavement appears to be relatively consistent. However, this finding should be viewed with some caution, because it may reflect at least, in part, the lack of studies which have specifically reported on performance relative to input variables, such as inflow concentration, hydraulic loading, and properties of the pavement.

Table 14.2 provides a summary of expected performance of porous pavements, based on the studies reviewed by Fletcher et al. (2003).

14.4.3 Maintenance

Porous pavements are permeable pavement with an underlying storage reservoir filled with aggregate material. Modular block pavements (including lattice block pavements) or permeable pavements overlie a shallow storage layer (typically 300 mm–500 mm deep) of aggregate material that provides temporary storage of water prior to infiltration into the underlying soils. Maintenance activities vary depending on the type of porous pavement (Table 14.3). In general, porous pavement should be inspected for cracks and holes, and removal of accumulated debris and sediment should be undertaken every three to six months. Depending on the design of lattice pavements, weeding or grass mowing may need to be undertaken. If properly maintained, and protected from 'shock' sediment loads, porous pavements should have an effective life of at least 20 years (Bond et al. 1999, Pratt 1999, Schluter et al. 2002 as cited in Fletcher et al. 2003).

14.4.4 Capital costs and maintenance costs

The capital cost of porous pavements is disputed, with conflicting estimates given, but consensus is that its cost is similar to that traditional pavement, when the total drainage infrastructure cost is taken into account Landphair et al. (2000). This conclusion is supported by a trial of several types of porous pavements, based on real case studies in the Puget Sound. The long-term maintenance costs remain relatively unknown, with no reliable Australian data available.

Some estimates of porous pavement costs were provided at a recent workshop run by 'Water Sensitive Urban Design (WSUD) in the Sydney Region' (www.wsud.org) in March 2003 (no maintenance costs were provided):

- permeable paving allowing infiltration: A$111/$m^2$
- permeable paving over sealed subgrade, allowing water collection: A$119/$m^2$

Table 14.3 Porous pavement maintenance issues

Design category	Maintenance activities and frequency	Equipment	Design attributes that facilitate maintenance activities
Modular block, lattice pavements or permeable pavements	Maintenance activities for porous pavements should be undertaken every 3 to 6 months and may include: • Inspection of pavement for holes, cracks and excessive amounts of accumulated materials • Removal of accumulated debris and sediment on surface of pavements • Hand weeding largely for aesthetic purposes • Mowing of grass if used between lattice pavements • Periodical removal of infiltration medium (about every 20 years) and replacement of geotextile fabric to ensure permeability is maintained to the underlying soils	• High suction vacuum sweeper and high pressure jet hoses • Gloves, spade, hoe • Lawn mower and waste removal vehicle • Bobcat or excavator and waste removal vehicle (e.g. tipper truck)	• Separate the upper 300 mm using geotextile fabric for easy removal and replacement of upper component • Recommended for **low traffic volume** areas only • Recommended for use in low sediment loading areas • Invert of system should be at least 1 m above impermeable soil layer and seasonal high watertable • Allowance should be made for a 50% reduction in design capacity over a 20 year lifespan

- permeable paving with concrete block paving: A$98/m^2 with infiltration, A$122/m^2 with water collection
- permeable paving with asphalt: A$67/m^2 with infiltration or A$80/m^2 with water collection
- permeable paving with concrete block: A$90/m^2 with infiltration, A$116/m^2 with water collection.

The Californian Stormwater Quality Association (www.cabmphandbooks.com) have produced a handbook for best practice stormwater management in new development and re-development (http://www.cabmphandbooks.com/Development.asp). The report draws on research undertaken by Landphair et al. (2000), who reported annual maintenance costs of about A$9700 per hectare per year. Little information was given on what basis this was calculated. Based on amortised construction and maintenance costs over 20 years, this equated to around A$9 per kilogram of TSS removed, inclusive. Landphair et al. also lament the lack of life cycle cost data for stormwater treatment measures, including porous pavements, and point out that both construction and maintenance costs are very site specific. Although some local data may be available, there are not the cost relationships which allow maintenance costs to be predicted for any given site.

14.4.5 Protection and maintenance of porous pavements

Along with evidence of many successful implementations of porous pavements, there are many instances of failure, because of clogging. *It is absolutely critical that porous pavements are protected from large sediment loads during and shortly after the construction phase.* Failure to do so could see the effective lifespan of the pavement reduced to less than 10% of the predicted lifespan.

14.4.6 Design and supply of porous pavements

There are several suppliers of both monolithic and modular porous pavement systems within Australia (although for commercial equality reasons they are not listed here). When seeking information from suppliers on their products, the following information should be sought:

- cost/m^2, including supply and installation (taking into account site conditions)
- required depth of installation and details of the subbase, geotextile and associated components
- maintenance requirements and pollutant collection processes for particular pavement
- independent performance data (infiltration capacity and pollutant removal)
- potential for application of porous pavement for only part of the paved surface (and effects on infiltration and pollutant removal performance).

14.5 Use of natural areas including reforestation and revegetation

Another technique considered worthy of consideration is the use of reforestation and revegetation measures. The following text, largely based on material contained in Auckland Regional Council (2003), should provide initial guidance to practitioners in this regard.

This technique involves the utilisation of existing areas of vegetation, from forested areas to scrub vegetation to pasture areas. The scale of this approach can be made to vary. In a micro sense, redirecting pathway and driveway stormwater runoff onto adjacent grassed or otherwise vegetated areas (also referred to as the minimisation of directly connected impervious areas), illustrates this concept of natural area use. All such opportunities should be considered where redirection can be done without causing problems, such as concentrated flow increasing slope erosion.

For those situations where vegetation already exists, use of that vegetation or enhancement of the vegetation is a good approach. Significant benefits can be gained also by reforesting or revegetating portions of sites that would improve an existing situation or restore a degraded resource.

Reforestation/revegetation includes the planting of appropriate tree and shrub species, coupled with the establishment of an appropriate ground cover around trees and shrubs in order to stabilise soil and prevent an influx of invasive plants and weeds. The practice is highly desirable because, in contrast to many other management approaches, reforestation actually improves in its stormwater performance over time.

Reforestation benefits relate closely to benefits cited in the literature on riparian stream **buffer** protection, although reforestation is not linear in configuration.

Plant species should be selected carefully to match indigenous species that exist in the area and care should be taken to use species that reflect the combination of environmental factors which characterise the area.

Reforestation areas need periodic management, at least for the first five years. This will ensure good survival rates for the newly planted stock. The level of management decreases as the plantings mature. During the first two to three years, annual spot applications of herbicide may be necessary around the planted vegetation to keep weeds from outcompeting the new trees and shrubs for water and nutrients.

To the extent that vegetation of different types is already established, the stabilised natural area offers various physical, chemical and biological mechanisms which should further maximise contaminant removal as well as attaining water quantity objectives.

14.6 References

Auckland Regional Council (ARC) (2003). *Stormwater Management Devices: Design Guidelines Manual (TPIO)*, 2nd edn, Auckland Regional Council, Auckland.

Bavor, H.J., Roser, D.J., Fisher, P.J. and Smalls, I.C. (1989). *Joint Study on Sewage Treatment Using Shallow Lagoon – Aquatic Plant Systems*, *Treatment of Secondary Effluent*, Water Research Laboratory, Hawkesbury Agricultural College, Richmond, NSW.

Cooperative Research Centre for Catchment Hydrology (CRCCH) (2003). *Model for Urban Stormwater Improvement Conceptualisation (MUSIC). User Guide, Version 2.0,* CRCCH, Monash University, Victoria.

Crites, R.W. and Tchobanoglous, G. (1998). *Small and Decentralised Wastewater Management Systems*, McGraw-Hill, New York.

Engineers Australia (2003). *Australian Runoff Quality Guidelines*, Draft, June.

Fletcher, T.D., Duncan, H.P., Poelsma, P. and Lloyd, S. (2003). *Stormwater Flow and Quality and the Effectiveness of Non-Proprietary Stormwater Treatment Measures; A Review and Gap Analysis*, The Institute for Sustainable Water Resources, Monash University and the CRC for Catchment Hydrology, Victoria.

Landphair, H., McFalls, J. and Thompson, D. (2000). *Design Methods, Selection and Cost Effectiveness of Stormwater Quality Structures (1837–1).* Texas Transportation Institute Research Report, College Station, Texas, USA.

Puqet Sound case studies (2003). http://www.psat.wa.gov/Publications/LID_studies/permeablepavement.htm. Accessed 26 August 2003.

Queensland Department of Natural Resources and Mines (2000). *Guidelines for Using Free Surface Constructed Wetlands to Treat Municipal Sewage*, Department of Natural Resources and Mines, Brisbane, Qld.