Recycled Organic Products in Stormwater Treatment Applications

Department of Environment and Conservation NSW

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Executive summary

Introduction

The sustainable diversion of organic materials from landfill requires economically viable markets to be developed for recycled organic products. The treatment of stormwater is an emerging use for recycled organic product blends which offers significant promise in terms of market potential and viability. One key barrier to the use of recycled organics in stormwater treatment options is the absence of a performance-based product standard. Such a standard will provide necessary credibility in the marketplace, thereby supporting stormwater engineers and land managers to include recycled organic products in their design considerations, and to specify the correct product for the specific application.

Pollution from urban catchments is a major problem in waterways, and in Australia this problem is compounded by extensive city and suburban development, and by large variability in flows. Urbanisation increases the area of impervious surfaces within a catchment and densely developed inner urban areas are almost completely impervious. This results in a greatly reduced amount of water able to infiltrate the soil and consequently, most rainfall becomes run-off. Best management stormwater pollution prevention is based on concepts of low impact development. This concept achieves stormwater management controls by changing conventional site design to create an environmentally functional landscape similar to the natural hydrological functions of a catchment. Urban waterways require management in order to protect these resources from the impacts of urbanisation. This involves managing the volume and rate of catchment run-off, the quality of the run-off and the habitats necessary for supporting a healthy aquatic community.

Recycled organic products for stormwater applications

Conventionally, stormwater drainage has been designed to provide the fastest possible transport of stormwater run-off out of the catchment into receiving waters. This conventional system has focussed on impermeable surfaces used to transport the run-off to receiving waters as fast as possible to prevent localised flooding. However, the transport of water from impermeable surfaces also results in the transport of pollutants and the pollutants eventually reach the receiving waters resulting in pollution and *contamination* issues. The pollution of receiving waterways from stormwater run-off has become a significant public issue particularly when recreational areas such as lakes and beaches receive these pollutants.

Recent developments in stormwater management have focussed on detention and retention of the water, pollutant removal and reuse. Recycled organic products can make a valuable contribution to a range of stormwater management options. New concepts in stormwater management are evolving that contrast the conventional stormwater drainage mentality of fast transport of water to receiving waters. These new concepts combine infiltration, distributed storage and treatment as well as delayed transport of the stormwater run-off. Such emerging technologies include permeable pavers, biofiltration, biological retention, infiltration basins and filter bales. These technologies are outlined below as they relate to applications incorporating the use of recycled organic products:

- Permeable pavers reduce the impermeable area of surfaces and allow infiltration of water, thereby reducing surface run-off. Permeable pavers can be installed above a layer of recycled organics products or blends to allow degradation of pollutants present in the stormwater;
- Biofiltration methods use more biologically active media such as soil or *compost* to treat the stormwater. Microorganisms break down the organic pollutants within the stormwater whilst it is detained within the filtration media;
- Biological retention or bioretention involves the use of a porous media covered by a mulch and vegetation plantings and has been suggested as a management practice for stormwater run-off;
- Infiltration basins are used to retard excessive flows of stormwater after large storm events by allowing the water to infiltrate into a porous biologically active media containing recycled organics. This substrate provides a means for degrading stormwater pollutants and the water is subsequently allowed to recharge to the groundwater system or can be collected for reuse or disposal in receiving waters;
- Filter bales are an emerging technology that use an organic media contained within a geotextile fabric to slow the run-off and filter the water through biologically active material. This results in biological degradation of pollutants as well as filtration of larger particles;

The minimum recommended analysis for stormwater installations utilising recycled organics include trace metals, physical particulates, industrial pollutants, nutrients and other chemical characteristics. These characteristics indicate the quality of the water in terms of physical and chemical pollutants. The three important characteristics of a successful recycled organic product blend for use in a stormwater installation are structural integrity, porosity and hydraulic conductivity.

The life span of recycled organics used in stormwater applications is dependent on the type of system, flow rate and volume of the stormwater, pollutant load of the stormwater and other factors including system design. A generic life span for this media cannot be specified due to these variables. A number of studies have reported life spans of up to five years for such media, however, these studies have involved biofiltration of odours and not stormwater.

After use in a stormwater management system, the contaminated recycled organics media can be reprocessed at a *composting* facility where further degradation and dilution of pollutants would occur when spent media is combined with other compostable organic materials and composted. Resulting composted products would be required to meet existing standards to be suitable for unrestricted application. This dilution, treatment and redistribution of the potentially contaminated media should pose minimal risk to human health or the environment.

The benefits of recycled organic products in stormwater applications may be significant. However, the main obstacles to the widespread use of this media are:

- The absence of a performance-based product standard which will increase user confidence and enable appropriate product selection and specification;
- The absence of cost/benefit data relating both to installations and ongoing maintenance (including the need for information on call back period for replacement of media);
- The absence of documented design guidelines for installations.

Investment in the development of robust, industry endorsed product standards and design guidelines could significantly increase the successful application of recycled organic products in stormwater treatment applications, thereby contributing to improved environmental management, *recycled organics industry* viability, and the achievement of ecologically sustainable development objectives.

Conclusions and recommendations

This report has identified and reviewed existing (publicly available) information regarding stormwater treatment applications incorporating recycled organic products. The review of available literature identified that limited studies have been conducted in this area, particularly in an Australian context. The review provides a baseline for industry and Government to pursue related recycled organics demand creation opportunities.

The recommendations of this report are therefore:

- To develop performance-based product standards for stormwater media incorporating recycled organics products;
- Review outcomes from the existing Manly Stormwater Management site once available to identify gaps in information relating to media performance, media longevity, maintenance costs and design;
- Develop and document design guidelines for recycled organics in stormwater treatment installations; and
- Establish a best practice case study installation in order to validate performance of standard products, quantify longevity of media and establish accurate costs relating to both installation and on-going maintenance and to inform refinement of both product standard and best practise design guidelines.

Section 1 How to use this report

1.1 Objectives of the report

One key barrier to the use of recycled organics in stormwater treatment options is the absence of a performance-based product standard. Such a standard will provide necessary credibility in the marketplace, thereby supporting stormwater engineers and land managers to include recycled organic products in their design considerations, and to specify the correct product for a given application. Research needs to be evaluated and compiled in the context of specific stormwater applications and treatment objectives to clearly identify the value and use of available research, to identify existing installations in Australia, and to support the development of documented performance specifications and manufacturing guidelines. A performance-based product standard would increase the acceptance of recycled organics in stormwater management options, enabling industry to accelerate the development of this new and emerging market.

The development of market specific performance-based products and market development strategies should be grounded in existing information and expertise. This project identifies existing studies produced both in Australia and internationally. The outcomes and methodology of this existing research is reviewed as pertinent to the development of performance-based product specifications for recycled organic products for stormwater applications.

The objectives of this report are to:

- Maximise the viable and beneficial use of compostable organic materials to maximise the value of existing research information relating to stormwater treatment applications incorporating recycled organic products.
- Inform a program for the development of performance-based product specifications for recycled organic products for stormwater treatment applications.

1.2 Who is the report for?

This review has specifically been developed for The Department of Environment and Conservation NSW to support the development of current and potential markets for recycled organic products for stormwater applications by:

- Identifying and collating available information relating to stormwater applications incorporating recycled organic products;
- Informing the development of performance-based product specifications for recycled organics products in stormwater applications; and
- Identifying existing installations of stormwater installations incorporating recycled organics in New South Wales.

This report will be of interest to:

- Local Government
- Stormwater industry
- Manufacturers of recycled organic products
- Marketers of recycled organic products
- Waste educators
- Industry consultants

1.3 How to use the report

The report is designed to provide an easy-to-read review of stormwater applications incorporating recycled organics and to inform the future development of market specific performance-based product specifications for such applications.

The review is organised in a manner that firstly provides a background to the use of recycled organics in stormwater applications and the nature of stormwater in urban areas. A literature review details various applications, performance specifications and monitoring requirements. A table of current installations in New South Wales is provided. Finally, information for available products and media are attached.

Where possible, nationally accepted terms have been used in the preparation of this report. Key terms in the text are written in italics and definitions are provided in the Glossary (Appendix 1).

1.4 Terminology

Terms used throughout this report have been officially adopted by the NSW Waste Boards [now The Department of Environment and Conservation NSW] in July 2000 in the form of the RO Dictionary and Thesaurus: Standard terminology for the New South Wales recycled organics industry (Recycled Organics Unit, 2002a). This document is freely downloadable from http://www.rolibrary.com.

Section 2 Introduction

2.1 Stormwater applications for recycled organic products

The treatment of stormwater is an emerging use for recycled organic product blends which offers significant promise in terms of market potential and viability. Unfortunately, technical performance requirements and product development work done to date has been applied to the development of product specifications which are commercially owned and therefore not available for use by the entire recycled organics industry.

2.2 Urbanisation

Pollution from urban catchments is a major problem in waterways, and in Australia this problem is compounded by extensive city and suburban development, and by large variability in flows (Duncan, 1999). Urbanisation increases the area of impervious surfaces within a catchment and densely developed inner urban areas are almost completely impervious. This results in a greatly reduced amount of water able to infiltrate the soil and consequently, most rainfall becomes run-off. In addition to these impervious surfaces, urban drainage networks are ultimately designed to remove run-off from areas as quickly as possible to reduce localised flooding. Therefore, the consequences of this urbanisation are (CSIRO, 1999):

- More rainfall converted to run-off;
- More frequent high flow events in creeks, rivers and receiving waters;
- Reduced lag time between rainfall occurring and run-off reaching a waterway due to piping and channelling of flow; and
- Reduced groundwater inflows to streams during dry weather, with a greater proportion of flows made up from human uses of water in the catchment (e.g. car washing, garden watering etc.).

Additionally, the increased flood volumes, peak discharges and velocities in urban waterways cause a significant increase in the amount of pollutants carried by the flow. Urban stormwater discharges may cause adverse effects on receiving waters depending on the characteristics of such discharges as well as the characteristics of receiving waters (Marsalek *et al*., 1999). Typical pollutant types and sources found in urban run-off are shown in Table 2.1.

Table 2.1. Common pollutants and likely sources found in urban stormwater (CSIRO, 1999).

Pollutant	Urban source
Sediment	Land surface erosion Pavement and vehicle wear Atmospheric deposition Spillage/illegal discharge Organic matter (e.g. leaf litter, grass) Car washing Weathering of buildings/structures
Nutrients	Organic matter Fertiliser Sewer overflow/septic tank leaks Animal/bird faeces Detergents (car washing) Atmospheric deposition Spillage/illegal discharge
Oxygen demanding substances	Organic matter decay Atmospheric deposition Sewer overflows/septic tank leaks Animal/bird faeces Spillage/illegal discharges
pH (acidity)	Atmospheric deposition Spillage/illegal discharge Organic matter decay Erosion of roofing material
Microorganisms	Animal/bird faeces Sewer overflows/septic tank leaks Organic matter decay
Toxic organics	Pesticides Herbicides Spillage/illegal discharge Sewer overflow/septic tank leaks
Heavy metals	Atmospheric deposition Vehicle wear Sewer overflows/septic tank leaks Weathering of buildings/structures Spillage/illegal discharges
Gross pollutants (litter and debris)	Pedestrians and vehicles Waste collection systems Leaf-fall from trees Lawn clippings Spills and accidents
Oils and surfactants	Asphalt pavements/road surfaces Spillage/illegal discharges Leaks from vehicles Car washing Organic matter
Increased water temperature	Run-off from impervious surfaces Removal of riparian vegetation

Urban run-off such as water washing off road surfaces, parking areas, vehicles and building materials can have affects on receiving waters that include oxygen depletion, eutrophication, species stress and toxicity. Urban run-off can contain nutrients at similar concentrations to treated sewage as well as significant levels of suspended solids, heavy metals and *pathogens* (Davis *et al*., 2001).

Best management stormwater pollution prevention is based on concepts of Water Sensitive Urban Design. This concept achieves stormwater management controls by changing conventional site design to create an environmentally functional landscape similar to the natural hydrological functions of a catchment. These include minimising discharge rates, run-off volume and run-off frequency to mimic predevelopment conditions.

Low impact development for stormwater pollution prevention can be accomplished in a number of ways, as described by Kunz (2001):

- Minimise impacts to the extent practicable by reducing imperviousness, conserving natural soils/ecosystems, maintaining natural drainage courses, reducing use of pipes and minimising clearing and grading;
- Recreate detention and retention storage dispersed throughout a site with the use of open swales, flatter slopes, bioretention techniques and similar designs;
- Maintain predevelopment time of concentration by strategically routing flows to maintain travel time; and
- Encourage property owners to use effective pollution prevention measures and to maintain management measures.

2.3 Stormwater characteristics

Non-point source pollution resulting from stormwater run-off has been identified as one of the major causes of the deterioration of the quality of receiving waters (Lee and Bang, 2000). Highway stormwater run-off has been identified as a specific source of pollution due to the chemical composition of this water. This chemical composition can include hydrocarbons, heavy metals, nutrients, phenols and herbicides (Marsalek *et al*., 1999).

The quality of stormwater can vary significantly depending on the surrounding environment. For this reason, the actual composition cannot be characterised, however, specific constituents generally tend to be present in stormwater produced in urban areas. Table 2.2 shows water quality data for urban run-off collected in the United States during a high number of rain events. This water quality data indicates the types of chemicals, and the concentrations of these chemicals, generally present in stormwater run-off.

Table 2.2. Urban run-off water quality data (Smullen *et al*., 1999).

Constituent	Units	Event Mean Concentrations		No. of events
		Mean	Median	
Total suspended solids	mg/L	78.4	54.5	3047
Biochemical oxygen demand	mg/L	14.1	11.5	1035
Chemical oxygen demand	mg/L	52.8	44.7	2639
Total phosphorus	mg/L	0.315	0.259	3094
Soluble phosphorus	mg/L	0.129	0.103	1091
Total Kjeldhal nitrogen	mg/L	1.73	1.47	2693
Nitrite and nitrate	mg/L	0.658	0.533	2016
Copper	µg/L	13.5	11.1	1657
Lead	µg/L	67.5	50.7	2713
Zinc	µg/L	162	129	2234

The general characteristics of stormwater in terms of physical, biological and chemical properties are discussed below. These characteristics detail the toxicity of the specific stormwater property and the common sources for contamination of urban stormwater.

2.3.1 Physical properties of stormwater

2.3.1.1 Suspended solids

Suspended solids are the materials that can be removed from a water sample by filtration under standard conditions. The greatest mass of suspended solids in urban run-off typically occurs in the 1 to 50 µm particle size range. Suspended solids can block pipes, change flow conditions in open channels and disrupt the habitat of aquatic invertebrates and fish. There is also an association between suspended solids and many other pollutants including hydrocarbons, heavy metals and phosphorus. The occurrence of suspended solids has frequently been used as a generic indicator measure of urban run-off pollution (Duncan, 1999). Suspended solids can arise from:

- Wet and dry atmospheric deposition
- Wear of roads and vehicles
- Construction and demolition operations
- Vegetation
- Wind and water erosion.

2.3.1.2 Oil and grease

Oil and grease are a composite of possibly thousands of organic chemicals with different properties and toxicities. This group is defined as any material soluble in an organic extracting solvent, but no solvent is completely selective for oils and greases only. Consequently, oil and grease concentrations are treated as indicative measures rather than analytically exact determinations (Duncan, 1999). Sources of oil and grease in stormwater include:

- Food processing and preparation
- Operation and maintenance of vehicles and machinery
- Natural compounds leached from vegetation and plant litter

2.3.1.3 Turbidity

Turbidity is the cloudiness in water caused by the presence of suspended matter such as clay, silt, colloidal organic particles, plankton and other microscopic organisms. Turbidity affects light penetration into a water body and interferes with disinfection in situations where water treatment is required (Duncan, 1999).

2.3.2 Chemical properties of stormwater

2.3.2.1 Total phosphorus

Total phosphorus in run-off is the sum of dissolved and particulate phosphorus (Duncan, 1999). Sources of phosphorus in stormwater include:

- Atmospheric deposition
- Tree leaves
- Domestic and agricultural fertilisers
- Industrial wastes
- Detergents
- Lubricants

2.3.2.2 Total nitrogen

Total nitrogen is the sum of total Kjeldahl nitrogen (organic nitrogen plus ammonia nitrogen) and oxidised nitrogen (nitrite plus nitrate). Nitrogen is an essential nutrient and may be limiting at a site, which could stimulate eutrophication of the water body if nitrogen levels increased. Rainfall is consistently the major source of nitrogen in urban run-off and inorganic nitrogen concentrations in rainfall often exceed a threshold level for algal blooms (Duncan, 1999). Other sources of nitrogen in stormwater include:

- Fertilisers
- Industrial cleaning operations
- Feed lots
- Animal droppings
- Combustion of fossil fuels
- Windblown pollen
- Spores
- Bacteria
- Dust
- Fallen leaves and other plant debris

2.3.2.3 Chemical oxygen demand

Chemical oxygen demand (COD) is a measure of the oxygen uptake of organic matter in a sample under the action of a strong chemical oxidant. Elevated COD concentration has reportedly been associated with roads and high urban land use and further increases have been noted in industrial areas (Duncan, 1999).

2.3.2.4 Total organic carbon

Total organic carbon is a measure of all carbon atoms covalently bonded in organic molecules. To a large extent, total organic carbon reflects the level of natural organic substances or humic materials in the water sample (Duncan, 1999).

2.3.2.5 pH

The pH of a solution is a measure of the hydrogen ion activity. The importance of pH in water quality is mainly due to the effect of pH on other quality parameters and on the chemical reactions in solution. The effect of pH on the solubility of a wide range of metallic pollutants is of particular significance (Duncan, 1999).

2.3.2.6 Total lead

Lead is a cumulative general metabolic poison that in animals becomes concentrated mainly in the bones. Lead bioaccumulates in animals, plants and bacteria and has been identified as an important pollutant of concern in stormwater research. Environmental and drinking water guidelines are frequently exceeded in urban stormwater (Duncan, 1999). Sources of lead in urban stormwater include:

- Petrol additives (main source)
- Tyres
- Industrial emissions
- Lead water pipes and soldered joints
- Plastic pipes and guttering
- Paints
- Lead roofs
- Flashing

2.3.2.7 Total zinc

Zinc is an essential and beneficial element in human growth and bioaccumulates easily in plants and animals. Zinc in stormwater is mostly associated with dissolved solids, although it will adsorb to suspended sediments and colloidal particles. Environmental guideline levels for urban stormwater are frequently exceeded (Duncan, 1999). Sources of zinc in urban stormwater include:

- Wear from tyres and brake pads
- Possible combustion of lubricating oils
- Corrosion of galvanised roofs, roadside fittings, pipes and other metal objects

2.3.2.8 Total copper

Copper is an essential element in human metabolism. Copper is toxic to aquatic organisms and is quickly accumulated in both plants and animals. Copper in stormwater is mostly associated with dissolved solids and colloidal material and environmental guidelines are frequently exceeded (Duncan, 1999). Sources of copper in stormwater include:

- Wear of tyres and brake linings
- Possible combustion of lubricating oils
- Corrosion of roofs and water pipes
- Wear of moving parts in engines
- Industrial emissions
- Fungicides
- Pesticides

2.3.2.9 Total cadmium

Cadmium is highly toxic and has been linked with some human cancers. Cadmium accumulates mainly in the liver and kidneys of humans and animals and tends to be concentrated by shellfish. Cadmium in stormwater run-off tends to be associated with dissolved solids and colloidal material (Duncan, 1999). Sources of cadmium in stormwater include:

- Combustion
- Wear of tyres and break pads
- Possible combustion of lubricating oils
- Industrial emissions
- Agricultural use of sewage sludge
- Fertilisers
- Pesticides
- Corrosion of galvanised metals
- Landfill *leachate* presumably contaminated by discarded rechargeable batteries

2.3.2.10 Total chromium

Chromium occurs in both trivalent and hexavalent forms with hexavalent chromium the predominant form in chlorinated or aerated water. Trivalent chromium is essential for human metabolism and is considered practically non-toxic, however, hexavalent chromium is associated with increased risk of cancer and is more toxic to aquatic organisms. Chromium in stormwater is mostly associated with suspended solids (Duncan, 1999). Sources of chromium in stormwater include:

- Corrosion of welded metal plating
- Wear of moving parts in engines
- Dyes
- Paints
- Ceramics
- Paper
- Heating and cooling coils
- Fire sprinkler systems
- Pesticides
- Fertilisers
- Corrosion inhibitors
- Sewage sludge applied to land

2.3.2.11 Total nickel

Nickel is essential for animal nutrition, is relatively non-toxic and does not accumulate in the body. Nickel in stormwater run-off is associated with suspended solids and organic matter (Duncan, 1999). Sources of nickel in stormwater include:

- Corrosion of welded metal plating
- Wear of moving parts in engines
- Electroplating and alloy manufacture
- Food production equipment

2.3.2.12 Total iron

Iron is widely distributed in the environment and is an essential element in human nutrition. Iron in surface waters is mainly associated with suspended solids (Duncan, 1999). Sources of iron in stormwater include:

- Corrosion of vehicles, roadside hardware and drains

- Burning of coke and coal
- Iron and steel industry emissions
- Landfill leachate
- Silt and clay particles
- Potable water supplies

2.3.2.13 Total manganese

Manganese is an essential element in human and animal nutrition and is regarded as one of the least toxic elements. Manganese occurs in a range of valence states and in both dissolved and suspended forms (Duncan, 1999). Sources of manganese in stormwater include:

- Wear of tyres and brake pads
- Steel manufacturing
- Manufacture of paints and dyes
- Fertilisers

2.3.2.14 Total mercury

Mercury is a highly toxic element that serves no beneficial physiological function. Mercury can exist in the environment as the metal, as inorganic salts and as organomercurial compounds such as methyl mercury. Fish and mammals absorb and retain methyl mercury to a greater extent than inorganic mercury and it is this form that mercury accumulates along food chains. Mercury causes a wide range of toxic effects in humans and is also toxic to fish and invertebrates (Duncan, 1999). Sources of mercury in stormwater include:

- Emissions from the chlor-alkali industry
- Coal combustion
- Paint industry
- Dental amalgam
- Run-off from gold mining sites

2.3.3 Biological properties of stormwater

2.3.3.1 Biochemical/Biological oxygen demand

Biochemical or biological oxygen demand (BOD) is an empirical measure of the relative oxygen requirements of polluted waters. The oxygen demand arises from the biochemical degradation of organic material, the oxidation of inorganic material such as sulphides and ferrous iron, and possibly the oxidation of reduced forms of nitrogen (Duncan, 1999).

2.3.3.2 Total coliforms

Total coliforms are used as an indicator of microbiological contamination of water. An indicator organism is not necessarily dangerous in itself, but indicates the likely presence of faecal contamination and hence the possible presence of pathogens in the sample. Total coliforms are a sensitive measure of possible faecal contamination since they are present in large numbers in the faeces of warm-blooded animals and can be detected at low concentrations (Duncan, 1999).

2.3.3.3 Faecal coliforms

Faecal coliforms are used as an indicator of faecal contamination of water. Faecal coliforms are a subset of total coliforms and are more closely associated with faecal contamination than total coliforms. *Escherichia coli* is a member of this group and is specifically of faecal origin (Duncan, 1999).

2.3.4 Stormwater management

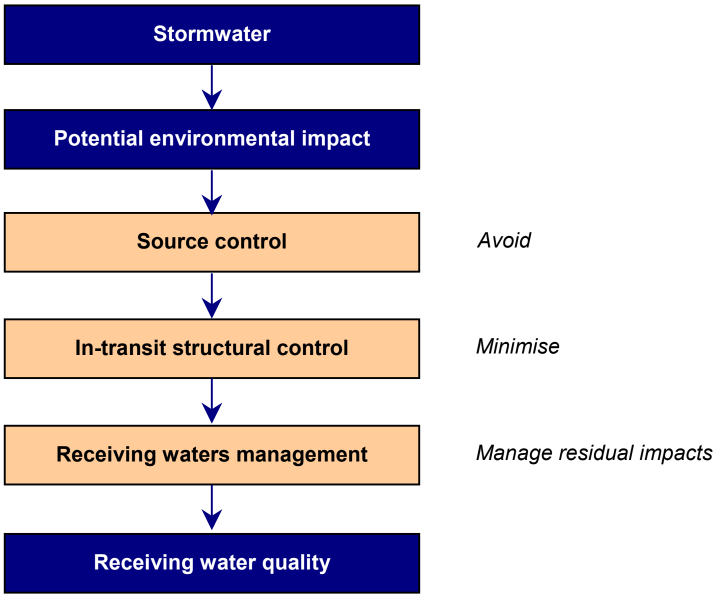
Urban waterways require management in order to protect these resources from the impacts of urbanisation. This involves managing the volume and rate of catchment run-off, the quality of the run-off and the habitats necessary for supporting a healthy aquatic community. Table 2.3 describes general threats to stormwater, the sources of these threats and impacts on the receiving water. This information should be considered when devising stormwater management plans to understand the extent to which existing and potential future activities may be a threat to receiving environments and waterways.

Table 2.3. Stormwater threats, sources and impacts on receiving waters (CSIRO, 1999).

Category	Impacts	Typical sources	Typical components
Pathogenic organisms	Closure of beaches Human infection Illness and disease	Sullage Sewer overflows Animals	Faecal coliforms Bacteria Viruses
Oxygen depleting substances	Low dissolved oxygen Smells Stress to aquatic life	Sullage Sewage overflows Animal waste Grass and leaf litter	Organic matter
Toxicants including metals and salts	Bio-accumulation Death of aquatic life	Cars Car parks and roads Processing industries Spills Atmospheric deposition	Pesticides Herbicides Petroleum products Lead Zinc
Sediment, including suspended solids and turbidity	Muddy waters Siltation Smothering of aquatic life	Stream erosion Construction sites Un-sealed roads Sand transport	Silt Sand Gravel Clay
Litter	Mainly visual Interferes with aquatic life	Commercial areas Fast food outlets Plant debris	Paper Plastic Leaves Dead vegetation
Nutrients	Promotes plant and algal growth Eutrophication (cyanobacteria algal blooms)	Sullage Sewer overflows Animals Sewage treatment plant discharges	Phosphorus Nitrogen
Flow	Increased volume or velocity of flows can scour or erode receiving waters Increased freshwater volumes can affect estuarine or marine environments	Increased stormwater run-off	Volume Frequency Velocity

Flood prevention and public safety are the fundamental objectives of stormwater management and these should be in no way compromised by changes to stormwater system planning and design in order to consider stormwater quality issues (CSIRO, 1999). Stormwater management is based on three principles that can be applied as part of an ordered framework to achieve environmental management objectives, as shown in Figure 2.1.

Figure 2.1. Stormwater management framework (CSIRO, 1999).

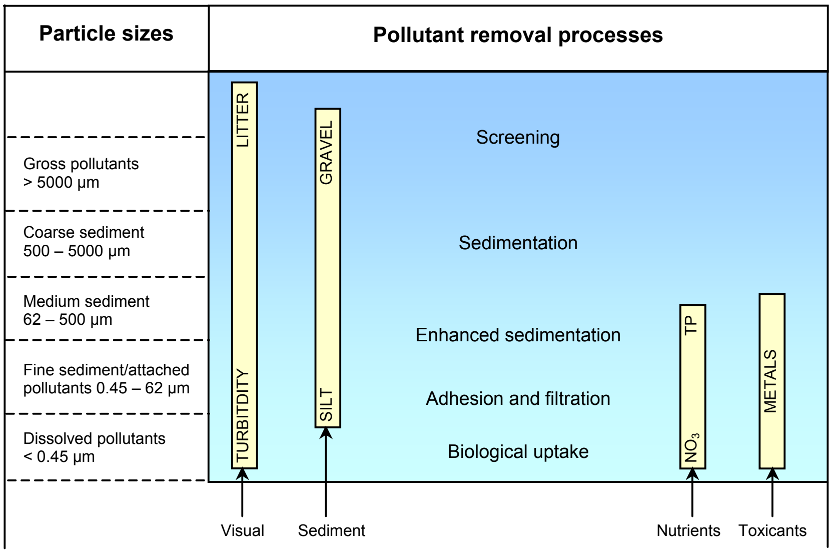


The three principles of stormwater management are (CSIRO, 1999):

- **Preservation:** preserve existing valuable elements of the stormwater system, such as natural channels, wetlands and streamside vegetation.
- **Source control:** limit changes to the quantity and quality of stormwater at or near the source. These measures can include land-use planning, education, regulation, design and operational practices to limit changes to the quality or quantity of urban run-off before it enters the stormwater system.
- **Structural control:** use structured measures, such as treatment techniques or detention basins, to improve water quality and control stream-flow discharges. This involves building structures to reduce or delay stormwater flow, or to intercept or remove pollutants after they have entered the stormwater system.

Where stormwater flows or pollutant levels remain too high, it may be necessary to manage the receiving environment itself by the use of bed and bank stabilisation techniques or by installing treatment measures such as floating litter traps, by implementing a clean-up program or by restricting certain uses of waterways.

Figure 2.2. Typical pollutants and treatment processes (CSIRO, 1999).



2.3.4.1 Stormwater treatment train

Stormwater management can involve the use of a ‘treatment train’ technique. This involves the use of structural treatment measures in a selected and sequential order to achieve optimal pollutant removal. No single pollutant trap can remove all pollutants. A treatment train technique can therefore be beneficial to remove stormwater pollutants due to the wide range of types and varying sizes of these pollutants. Figure 2.2 illustrates the typical pollutant types and size ranges that can be managed using various structural controls.

2.3.5 Stormwater management objectives

The environmental objectives of state policies can define the required water quality conditions of urban waterways. These environmental objectives can form the target for stormwater management, however, there are several ways to estimate the level of stormwater quality improvement necessary to ensure objectives can be met and the beneficial uses of the waterways protected. These improvements include (CSIRO, 1999):

- **Monitoring:** actual stormwater quality can be compared with receiving water quality to establish the level of treatment necessary to protect beneficial uses, where sufficient monitoring data are available.
- **Modelling:** stormwater quality and its potential impact on receiving waters can be mathematically modelled to determine treatment requirements. Some monitoring data are usually required to validate such models.
- **Generic values:** averaged values for typical urban stormwater quality can be compared to receiving water quality and objectives to indicate the level of improvement required.

The use of monitoring data for determining the required level of treatment of stormwater is the preferred method, however, variability in water quality experienced in waterways and stormwater systems results in the requirement of extensive monitoring programs to ensure sufficient data is obtained (CSIRO, 1999). More traditional stormwater management technologies are addressed elsewhere in *Urban Stormwater Best Practice: Environmental Management Guidelines* (CSIRO, 1999).

Section 3 Stormwater installations incorporating recycled organics

3.1 Traditional stormwater management solutions

Conventionally, stormwater drainage has been designed to provide the fastest possible transport of stormwater run-off out of the catchment into receiving waters. This conventional system has focussed on impermeable surfaces used to transport the run-off to receiving waters as fast as possible to prevent localised flooding. However, the transport of water from impermeable surfaces also results in the transport of pollutants and the pollutants eventually reach the receiving waters as well resulting in pollution and contamination issues.

The pollution of receiving waterways from stormwater run-off has become a significant public issue particularly when recreational areas such as lakes and beaches receive these pollutants. Also, the general opinion of water as a resource has increased, resulting in changed opinions as to the value of stormwater in terms of reuse options.

Consequently, recent developments in stormwater management have focussed on retention of the water, pollutant removal and reuse. Recycled organic products have played a significant role in the development of these stormwater management options and applications using such products are detailed below.

3.2 Applications for stormwater installations incorporating recycled organics

New concepts in stormwater management are evolving that contrast with the conventional stormwater drainage mentality of fast transport of water to receiving waters. These new concepts combine infiltration, distributed storage and treatment as well as delayed transport of the stormwater run-off (Ristenpart, 1999). The use of best management practice for stormwater installations is increasing to meet sustainable development objectives and to increase the quality of the environment and receiving waterways.

3.2.1 Permeable pavers

Permeable surfaces for roads and footpaths have been used as a means of disposal of stormwater in developed urban areas, as shown in Figure 3.1. These surfaces provide an alternative to impermeable surfaces, such as concrete, that would otherwise produce rapid stormwater run-off leading to possible flooding and degeneration of receiving water quality through the uncontrolled discharge of polluted urban waters (Pratt, 1999).

Newman *et al*. (2002) reported that highway run-off water quality could be improved by flow through a permeable pavement. Such pavements have been shown to be capable of degrading large quantities of clean motor oil due to the indigenous microbial biomass present within the pavement when provided with an adequate nutrient supply.

Recent developments in permeable paver design have included consideration of the underlying material of the paved area. The use of a porous soil is commonly used to absorb the run-off, however, an underlying media containing recycled organic products, such as compost, can result in a biologically active material capable of degrading the pollutants present in stormwater run-off.

Figure 3.1. Permeable pavers installed in Smith Street, Manly to aid in stormwater management.

3.2.2 Biofiltration

Biofiltration has evolved from more traditional stormwater management techniques, such as sand filters. Sand filters remove constituents from stormwater run-off primarily through a physical process of filtering out particulates from the water. The grain size of the sand determines the size of the particle that can be filtered out of the water and the flow-through rates. Filtration of water using various sand filter techniques has been occurring for approximately 100 years (Urbonas, 1999). Biofiltration methods use more biologically active media such as soil or compost to treat the stormwater. Microorganisms break down and/or immobilise the pollutants within the stormwater whilst it is detained within the filtration device.

3.2.3 Biological retention

Biological retention or bioretention involves the use of a porous soil covered by a mulch and vegetation plantings, and has been suggested as a management practice for stormwater run-off (e.g. Barvose and Hvitved-Jacobsen, 2001). Davis *et al*. (2001) reported that a detailed study of the characteristics and performance of bioretention systems found that heavy metals (copper, lead and zinc) and nutrients (phosphorous, nitrogen, ammonium and nitrate) could be removed to varying levels from a synthetic urban stormwater run-off in a laboratory study. Overall results support the use of bioretention as a stormwater best management practice and indicate the need for further research and development.

3.2.4 Infiltration basins

Infiltration basins are based on a traditional stormwater control measure of detention basins used to retard excessive flows of stormwater after large storm events. Infiltration basins are designed to detain excess run-off and allow the water to infiltrate into a porous medium such as the natural soil found on site. Further developments in this stormwater control measure use biologically active media such as

Figure 3.2. Infiltration basin located in Annandale used for detaining stormwater run-off from surrounding streets and filtering prior to discharge to Whites Creek and Sydney Harbour.

compost in the underlying soil substrate to provide a means of degradation and/or immobilisation of stormwater pollutants. Water can recharge to the groundwater system after permeating through the soil or can be collected for reuse or disposal in receiving waters.

3.2.5 Filter bales

Filter bales are an emerging technology based on traditional silt fence and hay bale filtering techniques. These more traditional methods work by slowing run-off, resulting in deposition of coarse material and some filtering through the textile or hay bale structure. Filter bales use an organic media contained within a geotextile fabric to slow the run-off and filter the water through the biologically active material. This results in biological degradation and/or immobilisation of pollutants as well as filtration of larger particles.

3.3 Benefits of using recycled organics

Stormwater applications incorporating recycled organics can be beneficial due to the filtration properties of the installations, which can result in cleaner water and reuse potential, and also due to the utilisation of recycled organics as a valuable resource as opposed to a waste material.

A further benefit of using recycled organics in stormwater installations is the ability of the media to degrade and/or immobilise the pollutants within the stormwater. This contrasts traditional methods of stormwater treatment that simply involve removing gross pollutants or filtering the water through filtration devices such as sand filters. Stormwater installations incorporating recycled organics contain a biologically active media capable of degrading and immobilising pollutants from the water resulting in cleaner water and degraded, less toxic compounds. The ability of recycled organics to degrade pollutants within stormwater is discussed in the following section.

3.4 Mechanisms of degradation

The characteristics of stormwater were detailed in Section 2.3 in terms of physical, chemical and biological pollutants. Stormwater installations incorporating recycled organics are increasingly being used in Australia due to the ability of this material to degrade and immobilise these pollutants through various mechanisms. This degradation ultimately results in the stormwater being less polluted allowing the water to be reused or discharged to receiving waters with a reduced threat to the environment.

The mechanisms of degradation/immobilisation of pollutants within the stormwater will be discussed in terms of physical, chemical and biological pollutants. The mechanisms will apply to the recycled organic material content, and not specifically to the type of installation, for example infiltration basin or filter bale technology.

It is important also to note that the characteristics of recycled organics vary significantly due to different compostable organic material contents, production methods and additives. Specifically designed recycled organic materials produced by different companies will have differing compositions. However, it is the general properties of recycled organic materials that will be discussed. The following section, Section 3.5, will examine the product specifications of the recycled organics in more detail.

Recycled organics primarily remove contaminants by the mechanism of biological degradation rather than accumulation of compounds within the organic material. Evidence for this biodegradation is listed by Wright *et al*. (1997) and is due to the negligible contaminant removal during the initial days of operation, the existence of biological processes such as lag and acclimation periods, and the large amount of contaminant mass removed over extended periods of time after biological acclimation processes are complete. Short-term removal of contaminants via biotic *adsorption* and absorption mechanisms is minor and the amount of contaminant mass that could accumulate in the media is small relative to the large amount of contaminant mass removed over an extended period of time (Wright *et al*., 1997).

3.4.1 Physical pollutants

The removal of physical pollutants such as suspended solids, grease and oils from polluted stormwater results in reduced turbidity. Particulate pollutants can be removed from stormwater using recycled organic products by a number of methods. Adsorption is the process whereby particulate pollutants attach to soil, for example clay or vegetation surfaces. Adequate contact time between the surface and pollutant must be provided in the design of the system, for example an infiltration basin, for this removal process to occur. Pollutants that can be removed via adsorption include heavy metals, phosphorus and some hydrocarbons (US EPA, 1999).

Filtration of the water can also occur as stormwater passes through the media. The media can trap particulate matter, however, filtering effectiveness may decrease with time. Common particulates removed from stormwater via filtration mechanisms include gross pollutants (trash, litter and vegetation larger than 5 mm), organic matter, phosphorus and suspended solids.

When developing recycled organics media for removal of physical pollutants from stormwater, the media must incorporate small particles to allow filtration of the water and removal particulate matter such as sediment. However, the flow of the water needs to be maintained to prevent flooding problems, particularly in times of high flow. Larger particles within the media would aid in flow-through of the water. Consequently, a relationship must be reached between filtration and flow-rate of the stormwater for physical pollutants removal.

3.4.2 Chemical pollutants

Chemical pollutants of stormwater can include excess nutrients such as nitrogen and phosphorus, heavy metals and pesticides. Adsorption, as previously discussed, can result in the removal of chemical pollutants such as heavy metals and pesticides from stormwater (US EPA, 1999). Such pollutants become bound to the organic content of the recycled organic material and can be degraded by microorganisms present in the media. The filtering mechanisms of the media can also remove chemical pollutants that may be bound to particulate material.

Stormwater installations incorporating recycled organics use the biologically active media to degrade the chemical contaminants. This is termed *bioremediation*. Bioremediation of toxic chemicals involves the application of microorganisms to detoxify or degrade the hazardous compounds and is reliant on the presence of large enough populations of the correct type of microorganisms and the proper conditions for the organisms to grow. The environmental conditions must also be suitable to promote the growth and metabolic activity of the microorganisms. Environmental factors such as temperature, inorganic nutrients (primarily nitrogen and phosphorus), electron acceptors (oxygen, nitrate and sulphate), moisture and pH are important to ensure optimum environmental conditions exist for bioremediation (Diaz *et al*., 1996).

Recycled organics media for removal of chemical pollutants from stormwater needs to allow for a sufficient retention time in order to degrade or remove the chemical pollutants through the mechanisms previously discussed. However, the water still needs to flow through the media, particularly in times of higher flow to prevent flooding. Again, the media must incorporate a variety of particle sizes to allow this to occur.

3.4.3 Biological pollutants

Biological pollutants that could potentially by present in stormwater include human and animal pathogens from sewage contamination or animal droppings. Pollutant uptake is a biological process that can occur in stormwater installations utilising recycled organics. Plants and microorganisms within the soil and media can be sustained via the uptake of nutrients from the soils or media and the filtered water. Woody plants can also retain these nutrients via storage in the plant itself over many seasons. Microbial activity within the soil aids in the removal of nitrogen and organic matter. Nitrifying and denitrifying bacteria remove nitrogen and aerobic bacteria are responsible for the *decomposition* of organic compounds (e.g. petroleum). Microbial processes require oxygen and can result in depleted oxygen levels if the installation area is not adequately aerated (US EPA, 1999).

Biological removal of stormwater pollutants requires a sufficient retention time in the media in order for microbial action to occur. However, the media must also allow the water to flow through the system as previously discussed. Consequently, development of this media must consider all the aspects of pollutant degradation in order to allow efficient removal and flow of the water through the stormwater system.

3.5 Product specifications

Stormwater applications incorporating recycled organics are ultimately an improvement on traditional stormwater treatment installations such as sand filters. Sand filters filter the stormwater through various sized grains of sand to remove pollutants. Utilising recycled organics material in place of sand has been found to be beneficial due to the high microbial activity of these products. Water filtration rates into this media are comparable to sand filters though the presence of abundant populations of microorganisms within the media results in the physical/biological removal of particulate matter and chemical adsorption.

The type of recycled organic material that can be used in stormwater applications varies widely between installations. A number of corporations have developed specialised media to be used exclusively in stormwater installations. This specialist media has particular components designed specifically to filter and degrade pollutants from stormwater run-off.

In general, there are a number of characteristics that are necessary for a successful recycled organic material use in stormwater applications. These characteristics are specific to the purpose of the media as opposed to use of compost as a soil conditioner or mulch. Specialist media tends to contain a mix of various recycled organic products as well as inorganic particles and bulking agents.

The three important characteristics of successful recycled organic material use in stormwater installations are:

- Structural integrity
- Porosity
- Hydraulic conductivity

In addition to these essential media properties, a successful system will require:

- Optimal microbial environment – nutrients, moisture, pH, and carbon supply should be non-limiting; and
- High moisture retention – moisture is critical in maintaining active microorganisms, however, microorganisms also require oxygen and so too much moisture may result in an *anaerobic* system. A sufficient infiltration rate will provide enough dissolved oxygen to prevent anaerobic conditions from developing.

3.5.1 Structural integrity

The structure of the recycled organic material needs to be such that compaction of the material does not occur over time. This is important, as hydraulic conductivity of the material will be reduced resulting in a decrease in the flow of water through the system. Ultimately, this could lead to flooding issues in times of high flow.

Recycled organic media used for biofiltration purposes needs to have an adequate structural integrity to prevent areas of saturation occurring within a system under times of high flow. Areas within the media that exhibit high or low moisture contents can inhibit microbial activity and oxygen penetration, which in turn would limit the degradation rates of pollutants within the system (Cárdenas-González *et al*., 1999a). Consequently, flow rate, duration and frequency of water detention within the system should be considered when media is developed or selected for a stormwater installation.

The media should also have a low bulk density (Swanson and Loehr, 1997). This reduces the compaction potential of the media and will allow more oxygen to penetrate the system and the water to flow more readily. The recycled organic media used in stormwater installations will often need to meet engineering requirements for compaction and load bearing capabilities depending on the installation. These need to be considered when developing or selecting the media to be used.

3.5.2 Porosity

The recycled organic material must have an adequate porosity to allow penetration of oxygen within the material. This is important for aerobic degradation processes and will reduce the retention time of the water within the system. Backpressure on the system will also be reduced as more water is allowed to penetrate the system rather than remain in the pipes.

A suitably porous media will also result in a large specific surface area. This maximises the attachment area, sorption capacity and number of reaction sites per unit medium volume (Swanson and Loehr, 1997). The larger surface area within contact with the stormwater will increase the degradation rate as more microorganisms are able to degrade the pollutants.

Lightweight bulking agents can be used in the media to increase porosity and reduce compaction. These components can include:

- Wood chips
- Perlite
- Vermiculite
- Polystyrene spheres

Bulking agents such as woodchips, offer structural benefits for stormwater installations due the rigidity of these components. This structure prevents compaction of the media and allows water to flow through the medium.

3.5.3 Hydraulic conductivity

The recycled organics material must also have a sufficient mix of particle sizes to allow filtration of the water to occur. Adequate porosity is required, as previously discussed, which demands large particle sizes to allow air penetration. For adequate infiltration, however, finer particles must be present to detain the water and allow sufficient contact with the microbially active components, to allow removal of pollutants and to ultimately result in degradation of these pollutants.

3.6 Disposal of recycled organic media

Biofiltration media commonly used in stormwater installations containing recycled organics can include compost, peat, bark, mulch and a combination of these. These materials possess many of the desirable qualities discussed previously, however, the main drawback of these types of material is the *mineralisation* of the organics that comprise the system (Swanson and Loehr, 1997). The aging of the media and compaction results in a limiting life for the material.

Stormwater installations incorporating recycled organics may require the media to be changed after a length of time. This amount of time will be dependant on a number of factors, including:

- The level of pollution within the stormwater
- The amount of water that is treated
- Large storm events
- Contamination, for example, due to road spillages
- Type of media and installation used

An issue to be considered when installing such a system is the requirement for disposal of the media after use in the installation. The media will tend to contain a number of pollutants such as heavy metals, pesticides and inorganic pollutants that may not have been fully degraded. These pollutants are likely to be significantly concentrated within the media due to the filtering mechanism of the system.

After use in a stormwater management system, the contaminated recycled organics media can be reprocessed at a composting facility (if required) where further degradation and dilution of pollutants would occur when spent media is combined with other compostable organic materials and composted. Resulting composted products would be required to meet existing standards to be suitable for unrestricted application. This dilution, treatment and redistribution of the potentially contaminated media is consistent with current industry practice and EPA guidelines for biosolids management, and should result in no significant risk to human health or the environment.

This is similar to the disposal of lower quality biosolids according to the *NSW EPA Environmental Guidelines for the Use and Disposal of Biosolids Products* (1997). Low quality biosolids can be used as *feedstocks* for composting operations as long as they are adequately diluted with other materials, such as *garden organics*, to reduce the concentration of chemical and organic contaminants. Contaminated recycled organics from stormwater installations could similarly be diluted with other feedstocks and redistributed as a composted product for various land uses.

Section 4 Literature review

4.1 Introduction

The use of recycled organics in various environmental applications is an area of research currently being pursued actively. High organic matter contents and biological activity of recycled organic products makes these materials effective for use in applications such as erosion control, biofiltration, stormwater management, bioremediation and wetlands construction.

Recycled organics are being increasingly used for stormwater and run-off applications whereby the filtering and pollutant capturing properties of products are valuable. High biological activity within recycled organic products renders them ideal to filtering contaminated water if the water is detained for such filtration to occur. Consequently, a number of products have been specifically designed to aid in water filtration by detaining the water and allowing contact with the microbially active recycled organics phase. A number of stormwater applications using recycled organic products, such as composts and mulches, are detailed below (e.g. Figure 4.1).

Figure 4.1. Compost berms at the base of slopes are effective for erosion and sediment control (Alexander, 1999).

4.2 Applications

4.2.1 Erosion control

Erosion control using recycled organics products is a relatively new and promising application. Research has shown that compost can often outperform conventional slope stabilization methods such as hydroseeding and hay/straw mulching (Alexander, 1999). Recycled organics products such as compost can be applied directly to slopes to improve the establishment of root systems and grass growth in poor soils such as landfills (Block, 1999). The application of recycled organic products aids in forming vegetation cover, returns organic matter to the soil and retains water resulting in reduced soil erosion.

When constructing erosion control structures, works are designed to carry a predetermined rate of run-off in order to minimise the chance of structural failure. This predetermined rate of run-off is the peak discharge and estimates of this rate are required before specifications for the erosion control structure can be determined. Peak discharge is influenced by catchment area, rainfall intensity and physical features of the catchment, such as slope and ground cover. Recycled organics used for erosion control can incorporate a wide variety of recycled organics media including garden organics compost, biosolids/garden organics co-compost, *agricultural organics* compost, poultry litter compost, municipal solid waste compost, biosolids compost, and wood mulch (Block, 2000; Risse *et al*., 2002).

Erosion control structures are not expected to last indefinitely or to handle the heaviest probable storm event. Such structures are designed to last for a certain duration, referred to as the return period or call back period. The design return period is related to the acceptable probability of the structure not failing within its desired lifetime. This is selected by considering the cost of repairs/maintenance or replacement and the implications of failure (Jackson, 1992). A high cost structure or one that would cause serious damage through failure should be designed using a longer return period (Table 4.1).

Table 4.1. Example of commonly used return periods for erosion control structures (Jackson, 1992).

Soil conservation work	Return period
Contour bank	5 years
Diversion bank	10 years
Waterways	15 to 20 years
Dams	20 to 50 years

The United States has seen compost used extensively for erosion control, particularly along roadsides (e.g. Goldstein, 2000; Codner, 2001; McCoy and Cogburn, 2001; Faucette and Risse, 2002; Goldstein, 2002). Methods of erosion control utilising recycled organics products include compost blankets, filter bales, filter socks and berms. These methods are detailed below.

4.2.1.1 Compost blankets

Compost blankets or composted mulch blankets can be used to cover slopes and to impede the flow of water. Soil particles are normally round and roll easily once displaced by water. The particles can gain momentum on slopes and displace other soil particles that can flow together in faster moving water creating rills, then channels and finally gullies. A compost blanket acts by absorbing the impact of water and reducing the flow momentum of the water and any soil particles, thereby reducing erosion (Tyler, 2001).

Recycled organic materials can be applied to slopes to act as a blanket to absorb the impact of rainfall or running water and to ultimately deter erosion of the slope. Wood residuals, consisting of a mix of bark, wood shavings, wood chips and wood scraps, have been reportedly effective at preventing fine silts and clay particles from accumulating in waterways. Wood particles used as mulch at a thickness of 2 cm or greater can reduce the amount of soil eroded by over 95% or more compared to an untreated surface (Demars *et al*., 2001).

A study was performed to quantify the properties and behaviour of mulches made from wood residuals as a medium to control erosion when applied to slopes at a thickness of 2 to 8 cm (Demars *et al*., 2001). The wood residuals included paper mill wood waste, pine bark mulch and ground stump/wood waste mulch. Fourteen test cells were constructed, three cells were left untreated but contained erosion control structures consisting of a silt fence, hay bales and a mulch berm situated at the base of the slope. Testing was done at a field site with a 1:2 slope. Results of the study indicated that wood waste materials are effective in minimising erosion when applied to the soil surface as an erosion control mulch at a thickness of 2 cm or greater and untreated soil surfaces produced over 50 times more sediment than treated surfaces during the trial. Other findings from the study included the effectiveness of wood materials in reducing run-off during storms events by absorbing rainwater and promoting percolation, and the ability of vegetation to root and grow through wood waste materials at a thickness of 2 cm resulting in increased erosion control.

A crucial component in the design of a compost blanket is ensuring that the water cannot flow under the surface cover. This can result in the water undercutting the compost blanket and can ultimately result in the material being transported away (Tyler, 2001). To combat this problem, compost filter berms are often used in conjunction with compost blankets to prevent this undercutting. Filter berms can be placed at the top of the slope to ensure a continuous cover and to prevent the water from penetrating under the blanket and gathering momentum to result in erosion.

4.2.1.2 Filter bales

Filter bales can include a number of different materials used to impede the flow of water, thereby reducing the sediment load of the flow, reducing erosion and pollution problems. Filter bales have been derived from more traditional methods, such as hay bales, that provide erosion control and deter the flow of water rather than filtering the run-off. Filter bales are an emerging concept for stormwater management and have developed from these more tradition methods of erosion control.

Modern filter bales are a relatively new innovation for erosion control using recycled organics contained within a geotextile fabric with structural support. Filter bale designs have been patented and represent an emerging technology for erosion control. These devices aim to reduce the movement of sediments and pollutants into drainage systems, such as stormwater systems, and to filter the water whilst still allowing it to flow. Such designs are a response to the increasing environmental concerns and regulations for particular industries such as construction and demolition.

A further advantage of filter bales is their durability and ability to be reused. Filter bales also tend to be lightweight and easily installed and are often constructed from recycled materials.

Such a product is produced by Atlantis Water Management whose product is constructed from recycled mobile garbage bins, battery cases and milk bottles (Figure 4.2). The filter bag is constructed from 300-micron (one third of a millimetre) pore size geotextile. The recycled organic material within the Atlantis filter bale is a bio-engineered soil media produced form garden organics and natural minerals (Atlantis Water Management, 2001).

4.2.1.3 Filter socks

Filter socks are a similar concept to the modern filter bales emerging on the market. These products are characterised by a flexible sock of geotextile material that contains recycled organic material to filter the water. Filter socks are versatile due to their flexibility as they can be bent around corners to direct water flow and are often used in conjunction with filter bales.

Atlantis Water Management also promote a product, the EcoSock, which is constructed from the same geotextile and recycled organic material as the filter bale, seen in Figure 4.2.

Figure 4.2. Atlantis Water Management FilterBale and EcoSock products comprised of a geotextile material surrounding a recycled organic material filter medium (Atlantis Water Management, 2001).

4.2.1.4 Berms

Silt fences have traditionally been used for erosion control on slopes and surrounding construction sites for many years. A silt fence is a sediment-trapping practice that utilises a geotextile fence along with the topography of the site and vegetation to minimise erosion. Compost installed in filter berms has been found to be an improvement on the traditional silt fence in keeping solids that are suspended and settled out of water sources moving on the surface (Tyler, 2001).

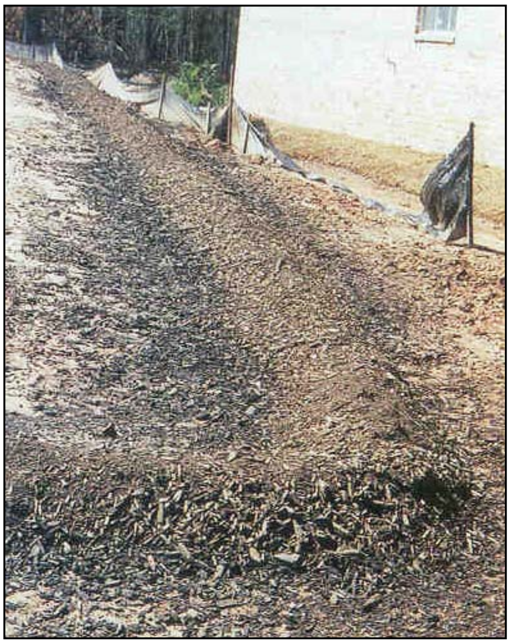
Ettlin and Stewart (1993) used compost in a number of erosion applications on a roadway with extremely steep slopes and compared compost applications to traditional erosion control methods. The research showed that silt fences are relatively ineffective in containing solids (Table 4.2). In comparison, various compost applications were highly successfully in detaining both settleable solids and suspended solids from the run-off. In particular, the compost barrier (or berm) at the base of the slope was very effective for erosion control and significantly more effective than the silt fence.

Table 4.2. Erosion control test results from parallel test plots on a 43% slope within a closed landfill site (Ettlin and Stewart, 1993).

Test plot application	Settleable solids (mL/L)*	Total suspended solids (mL/L)*
Control (untreated bare soil)	34.0	31,000.0
Silt (sediment) fence	32.0	26,000.0
Hydro-mulch	3.0	740.0
Mixed garden organics compost, medium, uniform slope cover	0.8	280.0
Mixed garden organics compost, coarse, uniform slope cover	1.4	690.0
Mixed garden organics compost barrier	2.6	1,300.0
Leaf compost, uniform slope cover	2.8	740.0

* Laboratory test results from run-off samples. Rainfall: 4 cm (duration not reported).

Figure 4.3. A compost filter berm replaces a failed silt fence, shown in the background (Goldstein, 2001).



Further research has shown that the use of compost berms at the base of slopes is effective for erosion and sediment control (Goldstein, 2001). Such filter berms are typically 0.5 m high by about 1 m wide and can be used in conjunction with, or to replace silt/sediment fences as shown in Figure 4.3.

Compost and compost blends typically are placed on up to a 2:1 slope at an application rate of 8 to 10 cm. The compost layer absorbs the energy of the rainfall and a substantial volume of the water, as well as reducing the flow velocity and improving percolation rates. Compost blends used in berms are typically made from a homogenous mix of fine and course (woody fraction) compost particles with 10 to 20% stone, bark, sand and/or gravel (Alexander, 1999). The compost blends are generally applied using a bulldozer, grading blade or pneumatic blower. Prior to the use of blowers, efficient application of compost was hard to achieve, particularly on 2:1 slopes (Tyler, 2001). The blower application method, coupled with the positive results from trials, has positioned compost berms as highly efficient and effective erosion control measures.

Tyler (2001) describes the advantages of compost filter berms as:

- Amends native soil, assisting in vegetation establishment and easy incorporation into the soil at completion of the job;
- Can be applied in areas where water has already accumulated;
- Can be applied in any direction or configuration or be adjusted to the outlines of designated areas;
- Lower cost than a silt fence and more effective in removing sediment and preventing phosphorus and other chemical leaching, therefore improving waterways;
- More effective at removing chemical compounds from run-off; and
- Compost is an annually renewable resource, all organic and natural.

In comparison, silt fences are less effective at containing suspended and settleable solids, are hard to maintain during construction projects and are often left on site at completion of project, which is unsightly. Silt fences are also constructed of non-recycled materials that require removal and reuse/disposal.

A study reported by Block (2000) used a berm of recycled organics constructed at the base of a slope and measuring 3.5 m high, 14.5 m wide at the base and 15 m long. The berm consisted of compost generated from source separated leaves and yard trimmings, food residuals, manure, agricultural and forest residues, soiled or non-recyclable paper, and woodchips. The berm was designed to slow stormwater velocity enough to allow sediments to be filtered out of the water. Soil that eroded from the slope was contained behind the filter berm. The berm was carefully dissected at the conclusion of the trial and it was found that little or no soil had penetrated beyond the first 5 cm of the berm.

A filter berm used around a construction site to primarily trap sediment is typically composed of a 50:50 mix of compost and mulch, shown in Figure 4.4. The proportion of mulch is increased if more rapid flow is needed, and the proportion of compost is increased if the water requires more treatment, for example trapping oil in the water (Goldstein, 2001).

An applied trial using wood residuals as a filter berm found that such an erosion control filter was more effective that either hay bales or a silt fence at controlling erosion from a 2:1 slope. The trial found that

Figure 4.4. A filter berm used around a construction site to trap sediment. This berm is constructed from a 50:50 mix of compost and mulch and applied using a pneumatic blower (Goldstein, 2001).

hay bales and the silt fence, although effective compared to no erosion treatment, released an order of magnitude more sediment than the filter berm composed of paper mill mulch (Demars *et al*., 2001). In general, mulch filter berms are used when the area is not to be reseeded, and compost filter berms would be used when seeding was to occur (Satkofsky, 2002).

4.2.2 Biofiltration

Biofiltration has traditionally been utilised as a biological air pollution control technology whereby waste gases are treated by passage through a biologically active porous medium, such as compost (Figure 4.5). The biofilter technology originated in Europe for removing odours from gases and over the past two decades have evolved to technically sophisticated products removing specific chemicals from industrial sources (Swanson and Loehr, 1997).

The primary fate of pollutants removed in biofilters is biological degradation rather than accumulation in the bed media. Evidence for biodegradation includes negligible pollutant removal during the initial days of biofilter operation, the existence of biological processes such as lag and acclimation periods and the large amount of pollutant mass removed over extended periods of time (Wright *et al*., 1997). Specific compounds that have been removed from waste gas streams with biofiltration include ammonia, carbon monoxide, hydrogen sulphide, acetone, benzene, butanol, ethanol, methane and toluene (Swanson and Loehr, 1997).

The majority of biofilters are used to treat air streams, for example to remove odours and volatile organic compounds (VOC) (eg. Wright *et al*., 1997; Jones and Bañuelos, 2000). However, more recent research has shown that they are suitable for treating contaminated water, such as stormwater or wastewater.

Compost can be used as a component of biofilter media due to the ability of compost to remove a wide range of compounds at relatively high contamination rates. Compost is widely used in biofiltration systems particularly for control of low concentration emissions of VOCs and odours. Compost media can provide the necessary requirements for good overall biofilter performance including high specific surface area; low pressure drop; high nutrient composition; high microbial diversity; good water holding capacity; and low cost (Cárdenas-González *et al*., 1999a).

Compost is typically used in biofilter media at an inclusion rate of 25% to 33% but rates can vary from 4% to 40% (Alexander, 1999). Other media components include bark, wood chips and ground wood, and compost can also be used as the only media. Compost-based biofilter media has a relatively long life span of 1 to 3 years, depending on the loading rate. Ideally, biofilter media should consist of the following characteristics (Alexander, 1999):

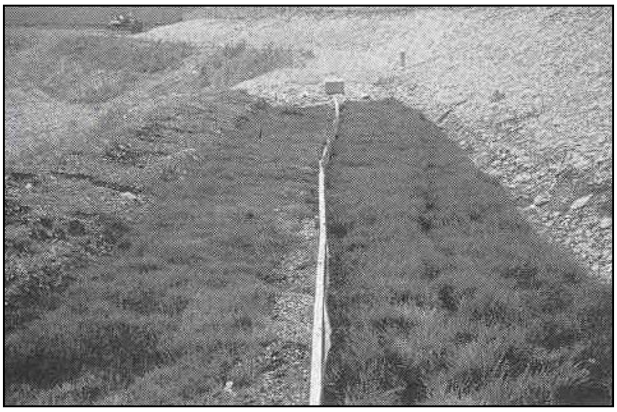
- Adequate porosity
- Adequate water holding capacity
- Supply of nutrients for microbial growth
- Uniform air distribution
- Does not shrink.

Cossu and Muntoni (1996) describe the advantages of the use of compost as a biofilter for leachate in a landfill. The compost biofilter can remove heavy metals from the leachate due to adsorption or complexation. Compost layers can also remove organic load, Ca and Fe ions from landfill leachate.

Lau *et al*. (2000) report that stormwater can be effectively treated using laboratory-scale biofilters.

Figure 4.5. Compost biofilters remove a wide range of compounds from air at relatively high contamination rates (Alexander, 1999).

Figure 4.6. Bioswales constructed from soil (left) and compost (right). The compost bioswales allowed for a faster, denser stand of grass (Alexander, 1999).



Such simple filters can be used to remove dissolved metals and sediment-absorbed metals commonly found in stormwater run-off. Over 90% of suspended solids and heavy metals were removed using this method after only 3 days and after 9 weeks, treatment efficiency was maintained and more than 90% of total Cu and Zn was removed from the stormwater.

Bioswales containing recycled organics are another application for the treatment of contaminated water. A bioswale is designed for an area of known surface run-off quantity and quality, such as car parks and roadsides. Bioswales are vegetated and allow the collected water to flow through the material where sediment and nutrients are captured and petroleum hydrocarbons degraded (Alexander, 1999).

A comparison between bioswales constructed using compost/soil and soil only reported that the bioswale containing compost allowed for a faster and denser stand of grass and higher removal efficiency in comparison to the soil bioswale (Figure 4.6). The compost was produced from garden organics and consisted of a 5 cm layer, later incorporated into the top 20 cm of soil. The compost bioswale also exhibited improved treatment of the water by reducing sediment, nutrients, heavy metals, total petroleum hydrocarbons and biochemical oxygen demand (Alexander, 1999).

4.2.3 The future of recycled organics in stormwater applications

The benefits of recycled organics product use in stormwater applications are potentially significant. However, the main obstacles to the widespread use of this media are:

- The absence of a performance-based product standard which will increase user confidence and enable appropriate product selection and specification;
- Absence of cost/benefit data relating both to installations and ongoing maintenance (including need for information on return period for replacement and/or maintenance of media);
- Absence of documented design guidelines for installations.

Investment in the development of robust, industry endorsed product standards and design guidelines could significantly increase the successful application of recycled organics in stormwater treatment applications, thereby contributing to improved environment management, recycled organics industry viability, and the achievement of ecologically sustainable development objectives.

4.3 Longevity of recycled organics used for stormwater applications

The life span of recycled organics used in stormwater applications is dependent on the type of system, flow rate and volume of the stormwater, pollutant load of the stormwater and many other factors. Consequently, a specified life span for this media cannot be given due to these variables. A number of studies have reported the general life span of recycled organics used in stormwater installations, shown in Table 4.3. All documented life span data identified during the literature review were from biofiltration installations used mainly for gas filtration (e.g. odours) and hence may not be directly comparable to stormwater installations.

Recycled organics media requires replacement over time due to degradation, build up of pollutants and other factors. Cárdenas-González *et al*. (1999b) report that compost used in biofilter operations for VOC and odour removal tends to deteriorate due to the activity of microbial populations, repeated wetting and drying, volatilisation and leaching of nutrients, gravitational forces and other factors. Consequently, compost biofiltration media is usually replaced every two to five years.

Table 4.3. General life spans of recycled organics material used in various applications.

Application	Components	Average life span	Source
Biofilter	Compost (25-33%), bark, wood chips, ground wood	1-3 years	Alexander (1999)
	Compost and wood mulch	2-5 years	Jones and Bañuelos (2000)
	Not specified	2-5 years	Cárdenas-González *et al*. (1999b)

The literature review identified limited information regarding the longevity of recycled organics used in stormwater installations. This indicates the need for further research in terms of monitoring the quality of the media and continuing performance over time under varying conditions. The relatively new nature of stormwater installations incorporating recycled organic products compounds this problem. As current installations such as the Manly Stormwater Project (see Section 5) continue, more information in regard to the ability of recycled organics to manage stormwater over time will become available.

4.4 Monitoring requirements

Stormwater applications incorporating recycled organics are a relatively new concept and hence a number of applications in New South Wales have undergone testing to determine the quality of the stormwater after treatment through these systems.

An example of a sampling strategy for monitoring the quality of stormwater treated using an installation incorporating recycled organics was performed by Australian Water Technologies for the Powells Creek installation at Concord (Australian Water Technologies, 1999). This sampling program collected stormwater samples upstream and downstream of the stormwater treatment system from ten wet weather events over a four-month period. Upstream samples were collected using an automatic sampler and flow measurement was monitored to allow calculations of discharge volume and rates of discharge. Downstream samples were collected from a detention tank. Samples were analysed for the following parameters:

- Physical parameters: turbidity, pH and conductivity
- Metals: copper, lead and zinc
- Nutrients: total phosphorus and total nitrogen

- Other: suspended solids, PAHs and faecal coliforms

The analytical techniques used to determine the above parameters are shown in Table 4.4.

Table 4.4. Analytical techniques for stormwater testing (Australian Water Technologies, 1999).

Water quality determined	Methods of field and chemical analysis	Units	Lower detection limits
Conductivity	WTW LF320 Conductivity Meter	µS/cm	-
pH	WTW pH320 pH Meter	pH units	-
Turbidity	Hach Turbidity Meter	NTU[1]	-
Faecal coliforms	Membrane filtration	cfu[2] 100/mL	1
Total phosphorus	Ascorbic acid reduction method using Aqua 800 Discrete Analytical System	mg/L as P	0.002
Total nitrogen	Hydrazine method using Aqua 800 Discrete Analytical System	mg/L as N	0.05
Suspended solids	Glass fibre filtration at 1.2 µm	mg/L	2
Trace metals (Cu, Pb, Zn)	Microwave acid digestion using ICP-MS	µ/L	*
Polycyclic Aromatic Hydrocarbons (PAHs)	High Performance Liquid Chromatograph	µ/L	0.1

Note: [1] NTU = Nephelometric Turbidiy Units; [2] cfu = colony forming units; * Varies depending on metal and sample condition.

The minimum recommended analysis for stormwater installations are shown in Table 4.5. These characteristics indicate the quality of the water in terms of physical and chemical pollutants. The categories of analysis include trace metals, physical particulates, industrial pollutants, nutrients and other chemical characteristics.

Table 4.5. Recommended minimum testing for stormwater run-off quality (Recycled Organics Unit, 2002c).

Category of test	Test
Trace metals	Pb Zn Cu
Physical	Suspended solids Turbidity
Industrial pollutants	Polycyclic aromatic hydrocarbons (PAH) Total petroleum hydrocarbons (TPH)
Nutrients	Total N Total P
Other chemical	pH Electrical conductivity Biological oxygen demand (BOD) Chemical oxygen demand (COD)

The on-going monitoring performed at the Manly Stormwater Project (see Section 5) will provide more information on the ability of recycled organics to manage stormwater and will further inform appropriate testing requirements for such installations.

Section 5 Installations

5.1 Stormwater installations incorporating recycled organics located in New South Wales

Table 5.1 details stormwater installations in New South Wales that use recycled organics products for stormwater management.

Table 5.1. Stormwater installations containing recycled organics products in New South Wales (New South Wales Government, no date; Resource NSW, no date; Atlantis Water Management, 2001; Environment Australia, 2001; Atlantis Water Management, 2002).

No.	Installation	Project participants	Type of system	Cost	Date	Monitoring
1	Whites Creek Annandale Infiltration Basin	Atlantis Water Management EPA Stormwater Trust Leichhardt Council	Stormwater infiltration basin	$77,500	Completed May 2000	yes
2	Guyra Urban Stormwater Point Source Trial	Atlantis Water Management Government of NSW Guyra Shire Council	Stormwater filtration and detention	$228,000	Installed December 1999	n.d.
3	Baulkum Hills Infiltration Channel	Atlantis water management Baulkum Hills Shire Council	Stormwater filtration and nutrient control	n.d.	June 1999	no
4	Manly Stormwater Project National Heritage Trust Grant	Atlantis Water Management Australian Water Association Manly Council Sydney Coastal Council The University of New South Wales	Stormwater filtration and re-use	$1,332,379	Installed June 2001	yes
5	Powells Creek, Concord	Atlantis Water Corportaion City of Canada Bay Council EPA Stormwater Trust	Stormwater filtration and re-use	$400,000	Installed December 1998	yes
6	Gaerlock Avenue, Tamarama	Atlantis Water Management EC Sustainable Environment Consultants Envirogreen Waverley Council DEC	Stormwater filtration	n.d	n.d.	no
7	Salt Pan Creek Landfill	Canterbury City Council EC Sustainable Environment Consultants DEC	Stormwater filtration	n.d.	n.d.	no
8	Kogarah Town Square	Environment Australia Kogarah Municipal Council	Stormwater collection, treatment and reuse	$629,000	Completion 2002	n.d.

n.d. = no data;

Section 6 Conclusions and recommendations

6.1 Conclusions

This report has identified and reviewed existing (publicly available) information regarding stormwater treatment applications incorporating recycled organic products. The review of available literature identified that limited studies have been conducted in this area, particularly in an Australian context. The review provides a baseline for industry and Government to pursue related recycled organics demand creation opportunities.

The benefits of recycled organic product use in stormwater applications are potentially significant as discussed in the review. However, the main obstacles to the widespread use of this media were identified as:

- The absence of a performance-based product standard which will increase user confidence and enable appropriate product selection and specification;
- The absence of cost/benefit data relating both to installations and ongoing maintenance (including the need for information on call back period for replacement of media); and
- The absence of documented design guidelines for installations.

Investment in the development of robust, industry endorsed product standards and design guidelines could significantly increase the successful application of recycled organics products in stormwater treatment applications, thereby contributing to improved environmental management, recycled organics industry viability, and the achievement of ecologically sustainable development objectives.

6.2 Recommendations

The treatment of stormwater is an emerging market for recycled organics product blends. However, one key barrier to the use of recycled organics integrated stormwater treatment options is the absence of a performance-based product standard. Such a standard will provide necessary credibility in the marketplace, thereby supporting stormwater engineers and land managers to include recycled organic products in their design considerations, and to specify the correct product for the specific application.

The recommendations of this report are therefore:

- To develop performance-based product standards for stormwater media incorporating recycled organic products
- Review outcomes from the existing Manly Stormwater Management site once available to identify gaps in information relating to media performance, media longevity, maintenance costs and design
- Develop and document design guidelines for recycled organics in stormwater treatment installations

- Establish a best practice case study installation in order to validate performance of standard products, quantify longevity of media and establish accurate costs relating to both installation and on-going maintenance and to inform refinement of both product standard and best practise design guidelines.

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Appendix 1 Glossary

All terms defined in this glossary are based upon definitions given in the Recycled Organics Industry Dictionary and Thesaurus, 2nd Edition (2002) unless otherwise noted.

Term	Definition
Adsorption	The process by which specific gases, liquids or substances in solution adhere to the exposed surfaces of materials, usually solids, with which they are in contact (Oxford English Dictionary, 2002).
Agricultural organics	Any residual organic materials produced as by-products of agricultural and forestry operations, including: weeds (woody and non-woody); animals (processing residuals, stock mortalities, pests), and crop residuals (woody and non-woody), and manures.
Anaerobic	In the absence of oxygen, or not requiring oxygen. Composting systems subject to anaerobic conditions often produce odorous compounds and other metabolites that are partly responsible for the temporary phytotoxic properties of compost. Anaerobic conditions are important for anaerobic digestion systems.
Bioremediation	Process by which microorganisms are stimulated to rapidly degrade hazardous organic contaminants to environmentally safe levels in soils, sub-surface materials, water, sludges, and residues. Also refers to the market segment within the recycled organics market sector which incorporates: Contaminated sites and soils; Water purification; and Biofiltration.
Biosolids	Organic solids or semi-solids produced by municipal sewage treatment processes. Solids become biosolids when they come out of an anaerobic digester or other treatment process and can be beneficially used. Until such solids are suitable for beneficial use they are defined as waste-water solids. The solids content in biosolids should be equal to or greater than 0.5% weight by volume (w/v). Biosolids are commonly co-composted with garden organics and/or residual wood and timber to produce a range of recycled organics products.
Compost	An organic product that has undergone controlled aerobic and thermophilic biological transformation to achieve pasteurisation and a specified level of maturity. Compost is suitable for the use as soil conditioner or mulch and can improve soil structure, water retention, aeration, erosion control, and other soil properties.
Compostable organics	Compostable organics is a generic term for all organic materials that are appropriate for collection and use as feedstocks for composting or in related biological treatment systems (e.g. anaerobic digestion). Compostable organics is defined by its material components: residual food organics; garden organics; wood and timber; biosolids, and agricultural organics.
Composting	The process whereby organic materials are pasteurised and microbially transformed under aerobic and thermophilic conditions for a period not less than 6 weeks. By definition, it is a process that must be carried out under controlled conditions yielding mature products that do not contain any weed seeds or pathogens.
Contamination (generic)	Any introduction into the environment or a product (water, air, soil, or recyclable materials) of microorganisms, chemicals, wastes, or wastewater in a concentration that makes the environment or the product unfit for its intended use.
Decomposition	The breakdown of organic waste materials by micro-organisms.

Term	Definition
Feedstock	Organic materials used for composting or related biological treatment systems. Different feedstocks have different nutrient concentrations, moisture, structure and contamination levels (physical, chemical and biological).
Garden organics	The garden organics material definition is defined by its component materials including: Putrescible garden organics (grass clippings); non-woody garden organics; woody garden organics; trees and limbs; stumps and rootballs. Such materials may be derived from domestic, commercial and industrial and commercial and demolition sources. Garden organics is one of the primary components of the compostable organics stream.
Leachate	Liquid released by, or water that has percolated through, waste or recovered materials, and that contains dissolved and/or suspended substances and/or solids and/or gases.
Mineralisation	The breakdown of organic matter into its constituent inorganic components, carried out chiefly by decomposer microorganisms, and, for carbon, during respiration when carbon dioxide is returned to the environment.
Pathogens	Microorganisms capable of producing disease or infection in plants or animals. Pathogens can be killed by heat produced during thermophilic composting.
Recycled Organics Industry	A range of related business enterprises involved in the processing of compostable organics into a range of recycled organics products, and the development, assessment, marketing, promotion, distribution and application of those products.
Resource Recovery	Process that extracts material or energy from the waste stream.

Appendix 2 Case Studies

Healthy Parks and Gardens – Stormwater Management

- Bear Cottage Hospice Development, Manly – Building site run-off treatment using recycled organics
- Gaerlock Avenue, Tamarama – Water purification using recycled organics
- M2 Motorway, Epping – Sediment run-off management using products containing recycled organics
- North Steyne, Manly – Stormwater run-off management using products containing recycled organics
- Powells Creek East Catchment, Concord West – Stormwater contamination treatment using recycled organics
- Salt Pan Creek Landfill, Narwee – Water purification/erosion control using recycled organics
- Whites Creek Valley Park, Annandale – Infiltration basin using products containing recycled organics

Appendix 3 Catalogue of Systems and Suppliers

Australian Native Landscapes

- Filterbales^{TM} – Brochure
- Stormwater treatment using infiltrating ecomedia – Information sheet

Soilco

- Filterbales^{TM} – Brochure
- Stormwater treatment using infiltrating ecomedia – Information sheet