EVALUATION OF FILTRATION MEDIA CONTAINING RECYCLED ORGANIC MATERIALS FOR STORMWATER TREATMENT

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Executive Summary

This document outlines a range of research opportunities associated with the evaluation of stormwater filtration media containing recycled organic materials and other inputs. The resultant blend of materials is an engineered soil called Enviro-media. This document describes the desired research outcomes from CORE and UTS researchers. It also describes the current state of the stormwater treatment field in Australia. It is recognised that the scope of the research activities contained within this report is greater than the current funding arrangements for the project will support. From this report it should be possible to select and prioritise the research activities that will best meet the needs of the current project but also provide scope for future work.

Application Context

There are many types of structural control strategies for stormwater treatment that could involve Enviro-media as a filtration media. Filtration media is used in many types of infiltrations systems including infiltration pits and dry swales (Fig. 1).

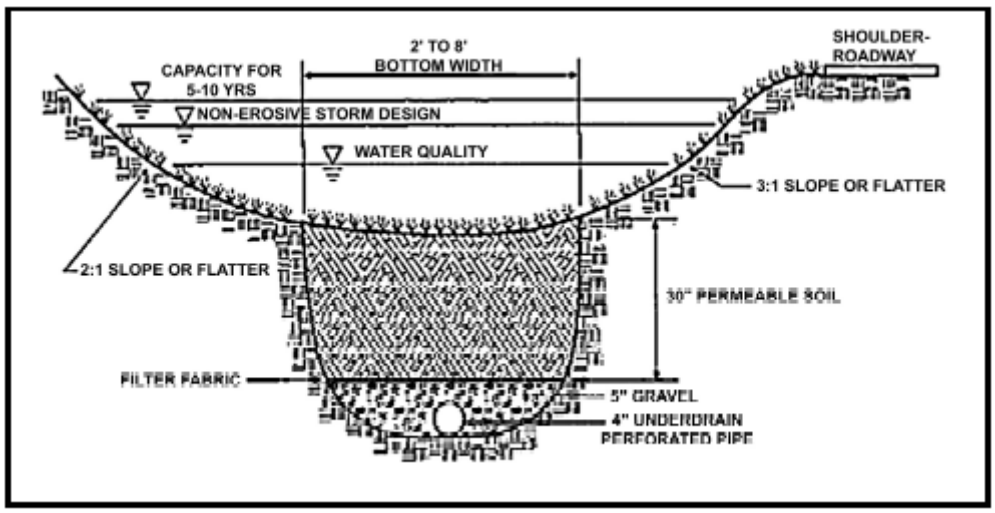

Figure 1 Typical infiltration system with filtration media located in a dry swale.

There are a number of different types of filter media which are used for stormwater treatment. These include sand, coated sand, perlite, leaf compost, zeolite, peat, granular activated carbon and other speciality media. There are few comparative tests between these different media reported in the literature (Clark et al, 1997). There is alsoalso a scarcity of design focused data which can be used to assess the pollution retention capacity of the media.

It was noted in reviewing the literature that there are large differences in the stormwater composition generated from various source areas. While the type of pollutants are important (metal, nutrients, hydrocarbon), of the upmost importance from a treatment perspective is extent to which those pollutants occur in a dissolved or particulate form. The removal of particulates from water is more dependent on the physical (ie grainsize) characteristics of the treatment media rather than the chemical (Cation exchange capacity, organic carbon, biofilm) characteristics. Therefore the advantages of a chemically reactive media (e.g compost) over a non-reactive media (sand) both which had similar physical characteristics may not be great when most of the pollutants occur as particulates. A much greater competitive advantage for chemically reactive media may be obtained when there are relatively high levels of dissolved contaminants. This was noted from the Stormfilter Leaf compost filter media where an emerging market for them is in dealing with stormwater from shipyards and other industrial sites (Lenhart et al, 2003). These sites have high levels of dissolved heavy metals and intermediate levels of particulates. Consequently there is a significant emphasis in this research agenda towards the development of the performance of the media with dissolved pollutants.

Proposed Methodology

The proposed methodology relies extensively on the use of experimental work and to a less extent forensic examination of existing installations to provide performance data. Laboratory test data is useful because it can be generated under controlled conditions which can be modified and generated in shorter time frames than field scale tests.

Activity 1: CHARACTERISATION OF STORMWATER & TREATMENT MEDIA

1a/ Stormwater Characterisation

Goal:

Identify physio-chemical characteristics of stormwater from various runoff sources

Discussion:

A preliminary literature analysis has suggested that stormwater runoff generated from different sources will have very different physio-chemical properties which will affect the efficacy of Enviro-media. Some characteristic types of stormwater include;

- road runoff
- sport field runoff
- acid mine drainage
- agricultural runoff
- industrial area runoff
- commercial area runoff

The broad categories for the physio-chemical classification of stormwater runoff may be generalised (Table 1).

Table 1: Parameter used for stormwater runoff studies

Pollution Categories	**Typical parameters**
Physical	pH, Hardness, Alkalinity, Apparent Color, DOC, COD, BOD, Electrical Conductivity
Particulates	Solids (total and suspended)
Nutrients	Total phosphorous, Orthophosphate, ammonia, organic nitrogen, nitrate-nitrite
Dissolved metals	Total and dissolved Zinc, Lead, Copper, Cadmium
Organic contaminants	Petroleum Hydrocarbons, Polyaromatic Hydrocarbons (PAH), pesticides and various chlorinated hydrocarbons. Various specific and lumped analyses are available
Major & Minor Inorganic Ions	Cations(Ca, Mg, K, Na, Li) , Anions(Cl, SO_4, F), Fe,
Microbes	Viruses, Bacteria, protozoa
Toxicity	Micro-tox

Methodology:

Conduct a review of the published literature which describes the physio-chemical characteristics of stormwater runoff. In particular, references to Australian data will be sought (e.g. Duncan, 1999).

Outcome:

Develop reference compositions for each of the identified stormwater source types. This will comprise numerical ranges for various parameters which are associated with the various pollutant categories. It will also identify issues that may need to be addressed about water quality implications of compost use for stormwater. This data will be used as the basis for designing synthetic stormwater for the laboratory studies. Identify whether surrogate compounds can be used to substitute for high toxicity organic compounds (e.g. PAH) in the laboratory studies.

1b/ Enviro-media characterisation

Goal:

Identify the biogeophysical properties of selected filtration media that may allow the prediction of Enviro-media pollutant retention performance.

Discussion:

Through published scientific work, there have been relationships established between the physio-chemical properties (Table 2) of filtration media/sediment and the capacity of media to sorb/treat stormwater contaminants. The validity of these relationships for Enviro-media mixes and its components (Table 3) needs to be tested.

Table 2: Potential pollutant retention mechanisms

Physio-chemical property of media	**Retention mechanism**
Organic carbon (%)	Sorption of dissolved non-polar organic compounds
Cation Exchange Capacity	Sorption of dissolved metals, polar organic compounds
Grain size distribution	Physical Filtration of suspended solids
Biofilm activity	Utilisation of dissolved nutrients
Biofilm mass (Physio-chemical property)	Sorption of particulate nutrients & metals

Table 3: Various filtration media types that could be evaluated

Media Types	**Media Types**
Enviro-media mixes (several current blends)	Perlite (Competitive product)
Zeolite (Enviro-media component & Competitive product)	Diatomaceous earth (Enviro-media component)
Sand (Enviro-media component & Competitive product)	Organic matter as fine mulch, mulch or conditioner (Enviro-media component)
Sand/peat (Competitive product)	Aggregate (Enviro-media component)
Wood chip	StormFilter Leaf Compost (Competitive product)

Methodology
Undertake analysis of selected media.

Outcome
This data is fundamental to trying to predict the behaviour of various Enviro-media blends which are made up of the component materials tested. It also underpins the "scientific" dimensions of the project. The validity of adding the performance of each component to give the performance of a blend will need to evaluated by testing a blend of known composition (even if it is not a current Enviro-media product).

Activity 2: PERFORMANCE OF SELECTED TREATMENT MEDIA THROUGH BATCH STUDIES

2a/ Batch tests for Multi-component Stormwater

Goal:
Identify the performance of selected filtration media under equilibrium conditions and with different different concentrations of synthetic stormwater.

Discussion:

A distinguishing feature of organic media (such as Enviro-media) is their ability to treat the dissolved fraction of the stormwater pollutant load through various retention/assimilation methods. Batch testing is a cost-effective approach for establishing the performance of media for dissolved pollutants. There is a need to better understand the chemical retention capacity of the Enviro-media constituents, Enviro-media blends as well as other filtration media currently being used for stormwater treatment. Given the diverse set of performance data which exists in the scientific and marketing literature there is a need to have comparable data.

Specifically this activity seeks to;

- predict the contaminant retention of an Enviro-media mix based on the performance of the components at equilibrium conditions between the stormwater and the media.
- assist the design of the optimal mix of components for particular stormwater runoff types.
- establish performance data which will allow the substitution of the Enviro-media components or blends for existing filtration media

Method:

Use batch sorption tests to establish isotherms which correlate pollutant retention of the media versus pollutant concentration in the stormwater. This data will be collected for at least four concentrations for each of the media selected for batch testing (Table 3). The stormwater used will be a multi-component solutions based on the reference solutions established from the Stormwater Characterisation part of the project. The methodology used for experimentation will conform to USEPA (1991) and be analysed in duplicate.

Outcome:

The isotherm data can be presented both graphically or as a numerical relationships. These isotherms comprise a graph of % pollutant sorbed versus concentration of pollutant in solution. Typical isotherms are shown in Clarke et al (1997). The resulting isotherm data may also be expressed mathematically for use in modelling. It may also be related back to the physio-chemical properties of the media (Table 2). If these relationships can be established then the behaviour of other Enviro-media based on their physio-chemical properties may be predicted. For some pollutants such as petroleum hydrocarbons and organic carbon content the relationship is more straightforward than for other pollutants. The isotherm is needed for modelling of contaminant flow through porous media.

2b/ Batch testing of parameter variation within the stormwater/media

Goal:

Establish better understanding of the treatment performance of various media under variable conditions.

Discussion:

There are a number of individual experiments which could be undertaken to establish the performance of the media in relation to the parameter of interest.

These tests could involve;

- Time variation: It is thought that the residence time within the filter may vary from several hours to days. The impact of different residence times on pollutant treatment for each of the pollutant categories is not known and is needed for Experiment 2a and for design advice. Most published equilibrium studies use three days as the reaction time. The experiment should consist of a minimum of six data points for several different media.

- pH & Ionic strength variation: It is known that metal assimilation and other polar pollutants by filter media are highly dependent on pH and ionic strength. The sensitivity of the pollutant treatment data generated in this project to these variables is need.
- Anaerobic/Aerobic conditions: It has been stated that under changes from aerobic/anaerobic conditions (such as may occur in a wetting and drying cycle) that pollutants may be desorbed back into the stormwater. The significance (if any) of this phenomena could be evaluated.
- Biofilm activity: The significance of a biological as well as chemical treatment within the organic filter media has not been clearly established from the literature. There is discussion of filter "ripening" in the literature. A simple batch test using a microbially inhibited and a microbially stimulated batch test for a sand media and an organic filter media may give some useful data.
- Colour generation: It is widely recognised that compost based organic filter produce higher levels of colour than other treatment media. Comparative data between compost media at various stages of maturation or between peat and Enviro-media could be collected from batch test data.
- Maturation of compost: The pollutant assimilation capacity of compost at different stages of maturation (composted vs pasteurised) is poorly understood. This impacts the choice of recycled organic materials to be used in Enviro-media. Also, does immature compost desorb previously sorbed pollutants as it matures within the stormwater treatment device/ Batch testing of compost at different stages of maturation may help define these issues. An indicator of compost maturation may be the C/N ratio.
- Structural and bio-physio-chemical integrity of the media while insitu: It would be expected that the Enviro-media being an organic media will undergo changes within a treatment device in response to the length of emplacement and dynamic interactions between stormwater and the media through wetting and drying cycles. The changes could impact the structural integrity (compaction, grain size distribution, permeability) or the bio-physio-chemical properties (sorption, desorption). Once the insitu environment of a typical insitu Enviro-media treatment device is adequately characterised then batch experiments can be used to test the significance of these processes.

Outcome:

These experiments outlined would be expected to provide useful data to develop a conceptual predictive model as well as focus on any issues that need to be addressed as concerns in the marketplace. The isotherm data for time variation can be used with data on Enviro-media hydraulic conductivity to establish bed depth needed for various level of pollutant removal.

Activity 3: PERFORMANCE OF SELECTED TREATMENT MEDIA THROUGH COLUMN STUDIES

3a/ Hydraulic performance of Enviro-media

Goal:

Identify the dynamic performance of selected filtration media using synthetic stormwater under different particulate loading regimes.

Discussion:

There is a need to establish hydraulic conductivity data and particulate loading data. The major uncertainty is that Enviro-media may be used in vastly different application contexts where there is no sediment pre-treatment (ie Filter socks) through to subsurface Enviro-media filtration where porous pavers and grass act as pre-filtration. Defining the level of pre-treatment expected will have a significant impact on the range of suspended solids concentrations and particle size distributions used. A useful set of data will be the field based data from existing installations (Activity 4). It would be proposed that a reference column filled with a fine-medium grained sand typical of that used in sand filter is also evaluated in addition to Enviro-media blend. This will allow comparative data interms of particulate clogging.

Methodology:

It is currently envisaged that the columns would be constructed from 1L graduated glass burettes. A Masterflex peristaltic pump will be used to pump a synthetic stormwater from a 200L drum.

Outcome:

The resultant data can lead to a graphical relationship between head-loss and suspended sediment concentration in the water.

3b/ Dynamic pollutant retention capacity of Enviro-media

Goal:

Identify the dynamic longer term behaviour of pollutant retention within Enviro-media

Discussion:

Column testing is often used to more dynamically simulated the performance of the material under conditions closer to those operating in the field. It is possible to combine Activity 3a and 3b.

Methodology:

It is currently envisaged that the columns would be constructed from 1L graduated glass burettes. A Masterflex peristaltic pump will be used to pump a synthetic stormwater from a 200L drum.

Outcome:
Tabular data showing influent versus effluent concentrations of pollutants.

3c/ Vegetative capacity of Enviro-media

Goal:
Identify capacity of Enviro-media to support the development of a vegetative cover and the impact of that cover on the pollutant retention capacity of Enviro-media.

Discussion:
A vegetation cover (e.g. grass) is used in several configurations of stormwater infiltration systems (e.g. swales). This cover serves as a pre-treatment to reduce the sediment load passing into the filter media as well as to increase the attenuation of dissolved nutrients in the stormwater. The nutrients can otherwise be problematic to remove. A competitive advantage of Enviro-media over other filtration media may be its ability to support the development of vegetation cover. However little is known about the biomass yields from the existing carbon and nutrients within Enviro-media and whether the biosorption properties aid the retention and subsequent use of applied fertilisers.

Methodology:
Columns used to evaluate the performance of vegetation range from flowerpots through to 200L wheelie bins. A large scale column would need to be located at a site where large quantities of stormwater were generated.

Activity 4: INSITU PERFORMANCE OF ENVIRO-MEDIA IN EXISTING STORMWATER TREATMENT INSTALLATIONS

Goal:
Understand the insitu performance of Enviro-media based on examination of material subjected to long-term use.

Discussion:
Enviro-media is believed to have potential in a diverse range of stormwater types. The performance of Enviro-media in these environments may be inferred from the batch testing processes in Activity 2. The application of Enviro-media to road runoff treatment has been undergoing application in the field for several years.

In particular, CORE has been involved in the following projects which may provide sites for further investigation (Table 4);

Table 4: Prospective sites for further investigation of insitu Enviro-media performance

Site name		Application type	Installed	Collected Data
Concord	Powells Creek	Insitu, in-line filtration, porous paver pre-treatment	12/1998	AWT (1999), 10 events.
Leichardt	Whites Creek	Annadale Sand Filter Treatment, Infiltration basin	5/2000?	Sydney Uni (1999), 7 events
Manly:	North Styne	Insitu, in-line filtration, porous paver pre-treatment	6/2001	Confidentiality?, Limited data collection to date?
Tamarama	Gaerloch Reserve	Drain infill	?	No monitoring data

Methodology:

Take core samples vertically through the Enviro-media within the stormwater treatment device. These core samples can then be subdivided and analysed as separate samples. The variability in the bio-physio-chemical properties of Enviro-media both laterally across the treatment area and with depth is not currently understood. For example, is the sorption of metals greater near the surface of the treatment device than deeper within the system? It may be possible to obtain a core from an area of the site which has had little flow which can serve as a background sample. This can be compared with the reverse engineered Enviro-media created from the specifications used during construction. Therefore some conceptualisation and characterisation of the treatment devices are needed if individual samples are to be considered representative of the behaviour of the entire system and of the Enviro-media itself.

Typically the steps to be able to evaluate the data from any field sampling would involve:

4a/ Site characterisation.

Identify the number of storm events from the available historical records of rainfall. From this an and actual stormwater composition monitoring data collected from the original project, it should be possible to estimate an expected pollutant loading that has occurred through the system since it was installed.

4b/ Enviro-media characterisation

Analyse the media for the selected parameters from which the performance of the media over the period of device operation can be ascertained. This characterisation would include parameters that would be expected to indicate a decrease in the physio-chemical performance of the system. This would include C/N ratio, Cation exchange capacity, organic carbon, phosphate and carbonate levels. To further substantiate any change batch/column testing against a reference stormwater composition could be measured. Batch testing could also address any issues about whether colour degradation of stormwater is a short-term or longer term issue. A relatively cost-effective approach for this project would be to conduct field based infiltration testing on various parts of the treatment installation to confirm what the insitu hydraulic conductivity of Enviro-media after it is several years old.

4c/ Performance evaluation at different sites

One goal of the analysis may be to ascertain the extent to which the pollutant front has moved through the media with a view to establishing the remaining life of the device. The contrast between site characteristics may give enough diversity to make general statements about Enviro-media performance under different conditions.

Outcome:

This work could be presented as longer-term evaluative case-studies. The specific parameters measured from the activity can be used to guide future design and answer market concerns about the longer term performance of the material.

Activity 5: DEVELOPMENT OF DESIGN AID/TOOL/MODELS

Goal:

Develop tools, aids or models which improves the capacity of design engineers to effectively use Enviro-media and shows its effective use.

Discussion:

There are many stormwater design manuals which contain step by step procedures for design infiltration systems. There is little existing performance data on either organic filter media or Enviro-media which can used within this design process. It is important that the fundamental engineering design data is widely available. The data generated by this project can provide the basic performance data that will need to be transformed into design focused data which can then be readily utilised.

The key relationships/data that would be needed to support the design process are;

- Suitability of the media for a particular application
  - Comparative pollutant removal performance data for different filtration media
  - Expected performance of the media under stormwater which are outside the range of the tested waters.

    - Features of Enviro-media in relation to other filter media (e.g. biosorption capacity, engineering strength of media)
    - Expected design life of Enviro-media
    - Considerations for different types of infiltration devices (eg vegetated surfaces, swales, infiltration pits) and different climates.

- Design of infiltration systems
    - Expected hydraulic conductivity of filter media for a given sediment loading
    - The percentage removal of specific dissolved heavy metals and nutrients for a given hydraulic residence time within the media
    - Calculation of the required bed height/thickness to achieve a particular level of dissolved pollutant removal

There are a number of different approaches that could be used to promote effective design. These include;

1) Worked examples of how to design Enviro-media into different infiltration systems.
2) Real case studies or scenarios which illustrate various designs and their performance
3) Development of an indicative predictability model. This model would use design guidelines as a basis to indicate the likelihood of achieving a particular design outcome. It would most likely consist of a series of linked HTML pages with possibly some simple numerical calculations.
4) Development of a numerical predictive model. This model would predict pollutant transport within the infiltration system in response to rainfall, porous media characteristics, vegetation cover, pollutant type (metals, nutrients), pollutant phase (dissolved, attached) and pollutant concentration. Both commercial and public domain models of varying sophistication are available. The models however are not specially designed for various stormwater infiltration devices but rather agricultural studies or landfill design.

It is believed that the Options 1 and 2 are likely to be the most cost effective strategies to promote effective design. They could be disseminated as technical literature and possibly in trade type stormwater journals. It is thought that most engineers refer to the design processes with the stormwater manuals when undertaking the detailed design of these infiltration systems. This may be due to diversity of design configurations. Option 3 is suited to aiding design decisions where there are clear guidelines and judgement that can be implemented in a logical flow process. It would require a computer programmer and atleast 100 hours of development. To develop code for Option 4 is beyond the scope of this project. It may be possible to calibrate one of the existing codes using case study or laboratory column data.

Outcome:

The expected outcomes based on Option 1 and 2 would be numerical design data (e.g. hydraulic conductivity), graphical design and comparative data (pollutant removal data for different media) and contextualised design data (case studies and worked examples).

PROJECT OUTCOMES DESIRED BY RESEARCH PARTNERS

CORE: Centre for Organic and Resource Enterprises, key desired outcomes

1. Characterisation of typical contaminant types in each type of stormwater run-off listed below and the development of typical high, medium and low contaminant thresholds for each type.
2. Quantification of the optimal recycled organic material content of an enviro-media mix in order to achieve the optimal contaminant removal from the certain types of stormwater flow (and possibly other contaminant run-off as outlined above).
3. Quantification of the physical, chemical (primarily UTS) and biological (primarily New Edge Microbials) efficacy of enviro-media mixes at certain application thicknesses.
4. Quantification of the contaminant build-up and optimal duration of the enviro-media to perform based on typical storm events measured over a 5 year period (condensed into testing period of February/March to November as discussed and proposed by the UTS).
5. The production of an efficacy model for each enviro-media type that includes the inclusion of potential "real-life factors" (such as the effects of plants in phyto-remediation) and potentially various uses such as swales, drainage cells and so on.
6. CORE sampling of stormwater treatment media at three of the following sites Concord, Manly, Leichardt and Tamarama to determine the possible contaminant removal at these sites based on reference mixes.

References

Clark, Shirley, et al. (1997, October). Pollutant Removal Capacity of Stormwater Filtration Media—Breakthrough Tests. Poster presentation at the Water Environment Federation Conference—70th Annual Conference and Exposition, Chicago, IL, 18-22. http://www.stormwaterinc.com/literature/pdfs/uofa_csf1.pdf

EPA (1991), Batch-Type Procedures for Estimating Soil Adsorption of Chemicals, Technical Resource Document, EPA/530-SW-87-006-F

Lenhart, J. H, deRidder, S., Calvert,P., Noling, C (2003) The Removal of Soluble Heavy Metals from Non-Point Source Runoff Originating From Industrial Sources by Leaf Compost Media, Presented at the New Zealand Water & Wastes Association Conference in Auckland, New Zealand, May 2003, http://www.stormwaterinc.com/pdfs/LenhartSolubleMetals.pdf