Centre for Organic Research & Education

**CORE Specification**

**Validation Report**

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# Validation Report

The following document is prepared by the not for profit Centre for Organic Research & Education Inc., (CORE) to support the CORE filtration media specifications (Annexure 1). The validation report contains results from a sample of the rigorous scientific studies that underpin the CORE Specifications. Validation is carried out on materials in local jurisdictions with currently 40 materials having been extensively studied. The material validation, manufacturing and supply system characteristics of the CORE authentication process can ensure that consistent bio filtration media performance can be relied upon in any jurisdiction to produce the most appropriate "fit for purpose" media formulation configuration. CORE media systems are suitable for use in vegetated and non-vegetated applications including stormwater, trade waste water and secondary treated effluent.

## What's the difference between media systems?

The fundamental difference between media systems (e.g. FAWB/ CRCWSC and CORE Organic Media) is the higher organic matter and material nutrient content characteristics of organic media. Practitioner concerns about environmental consequences of higher organic content (e.g. leaching), the use of recycled materials and the variable nature of media from excavated natural soil deposits means that material characterisation, performance analysis and quality control systems must be validated to ensure reliable system performance. The CORE classification system identifies intrinsic material characteristics that enable functional consistency of each validated manufacturer's media formulations.

The CRC for Water Sensitive Cities (CRCWSC) published "Adoption Guidelines for Stormwater Bio filtration Systems, 2016" essential specification's state that for its systems, filtration media formulations must not exceed 5% organic matter content and that the nitrogen content of materials must not exceed 1000 mg/kg, otherwise significant leaching will result.

CORE's 10 year research program has analysed many different types of organic materials. Studies (e.g. McLaughlin, 2008, Lucas et al, 2012, 2014, 2016,) confirm that there are those organic materials that display high leaching characteristics (e.g. labile organic matter). However significant leaching is not characteristic for many other, more stable organic materials. CORE studies have shown that some leachate contains properties that benefit plant establishment and growth.

Research cited in the FAWB specifications (Bratieres et al, Hatt et al.- 2008) that provides the basis for the conclusions on organic matter leaching behaviour is incomplete as the intrinsic characteristics of the type of organic matter studied is not identified. Neither was the composition of the leachate fully studied. Therefore there are no descriptors for manufacturers to select or analyse the 5% organic matter fraction required by the CRCWSC/FAWB specifications. This lack of clarity has led to variable performance results and some system failures being observed in the market with CRCWSC/FAWB specification media. Hence the expressed need of the Stormwater Quality Improvement Device (SQID) sector for a validation systems for natural systems.

Since the publication of the CRCWSC Adoption Guidelines Specification in September 2015, the CRCWSC have publically acknowledged that other filter media systems with higher organic content could perform as well as the CRC/FAWB specification and that organic and nitrogen content do not necessarily lead to leaching.

The CRCWSC acknowledgment is based on conclusive CORE research data demonstrating that high organic (up to 65%) and nitrogen content materials (over 1000 mg/kg) can be comparable in leaching behaviour and performance to products meeting the FAWB/CRCWSC specification. Organic media manufactured to the CORE Specifications, using a significant percentage of recycled material and higher organic content, are at least comparable in performance, quality and value.

## Validation studies

Studies and analysis in the following examples include the validation process applied to a range of organic components and reference media formulations and to a product (M165) supplied to the FAWB/CRCWSC specification. The results show that effective results can be achieved by the FAWB specification material studied in all performance areas. However there can be significant varied performance between different manufacturers. Research has identified that different materials can perform in significantly different ways (Lucas, 2012, 2014, 2016) under different water quality scenarios. CORE validation can ensure that the components used are fit for the performance purpose required.

The following example is provided to demonstrate typical results from materials that have successfully met the requirements of the validation process. The examples are based on results from proprietary products provided by manufacturers of bio filter materials and formulations that have been through the process and been granted validation status. Materials from various jurisdictions in Australia and overseas have been through the validation process. Product names have been coded to protect the confidentiality and IP of the individual manufacturers consistent with the requirements of the Australian Research Council Code for the Responsible Conduct of Research.

The validation process results from over 10 years of independent longitudinal research including studies by University of Newcastle (UoN), University of Technology Sydney, University of NSW and Melbourne University and wide consultation with manufacturers and end users in the public and private sectors. Resultant methods and processes underpin the various CORE Specifications for bio filtration media systems and form part of the system's continuous improvement process. A methodology synopsis is provided as an annexure to this report.

The intention of this report is to publish the performance results of the filter media validated to the CORE system so that subsequent specifications can be incorporated into sustainable procurement practices consistent with the Local Government Act and included in professional training programs with the aim to increase the use of recycled materials in bio filtration systems.

Validation results from the testing of materials to a repeatable process. Analysis focuses on results from waters with high and low, conservative and non-conservative pollutant concentrations. While other more specific material tests are conducted during the validation process the primary performance factors in this report focus on:

- Pollutant removal efficacy.
- Hydraulic conductivity including PSD analysis.
- Life span prediction.
- Leaching behaviour.
- Surface vegetation integrity.

**Validation Process description**

An expert inspection of potential organic and non-organic materials is conducted and a *prima face* case established for material suitability. Observably unsuitable materials are rejected at this point. Preference is given to materials of recycled origin.

The material validation system commences with baseline laboratory analysis where some materials are eliminated due to ineffective performance attributes or unacceptable characteristics such as high, undesirable leaching behaviour. This is identified in elemental and characterisation analyses. Numerous studies have resulted in the development of a classification system that enables materials homogenisation based on analyses of desired inherent attributes and alignment of relative characteristics. Effective materials are categorised according to homogenised characteristics before testing begins on the performance efficacy of these in reference formulation media.

Relationships are established between specific characteristics and the resultant performance attributes of each material and reference formulation. This enables subsequent manufacturers' proprietary formulations to be tailored for the specific performance requirements of particular systems. The result is a validation system methodology that ensures that the components and formulations used in a filter media design are of dependable quality, known performance within an acceptable range and fit for purpose. Subsequently manufacturing warranties can be offered.

Manufacturing to the CORE Specifications can be achieved by any filter media manufacturer using suitable (validated) proprietary ingredients and formulations. CORE Specifications contain the elements that are considered essential for bio filtration manufacturing to the system, however the Specifications do not constitute the entire spectrum of studies examined in the validation process. CORE only validates those materials, formulations and individual manufacturers that have formally completed the entire validation process. Manufacturers' proprietary materials and formulations must fall within specified operational and performance parameters to be validated.

The following report provides data from materials and formulations that have completed the validation process. A databank of over 40 Australian and International materials and formulations is being progressively constructed.

## 1. MATERIAL CHARACTERISTICS

Table 1 identifies examples of characterisation analysis conducted on component materials submitted for validation. Data sets are shown for: graded sand; categorised carbon materials (RO - CAT 1, 2 & 3); and samples of CRCWSC/FAWB and CORE Specification Reference Formulations (RFM1 & RFM2) made from the categorised components. These data are used to identify characteristics required to meet CORE or CRCWSC/FAWB Specifications.

Table 1 identifies CORE Specifications' similarity with M165 (FAWB/CRCWSC spec) in infiltration rate ($K_{sat}$). The table also identifies media characteristics that influence treatment and vegetation performance.

***Table 1 – Sample material characteristics comparisons***

| Test Parameter | Method Description | Method Reference | Units | RO-Cat3 | RO-Cat2 | RO-Cat1 | Graded Sand | CRCWSC /FAWB | RFM1 | RFM2 |
|---|---|---|---|---|---|---|---|---|---|---|
| pH (1:5 in H20) | Electrode | R&L 4A2 | pH units | 7.76 | 7.87 | 9.23 | 7.72 | 6.8 | 8.29 | 7.74 |
| pH (1:5 in CaCl2) | Electrode | R&L4B2 | pH units | 7.18 | 7.31 | 8.15 | 6.74 | 6.38 | 7.45 | 7.28 |
| Chloride Soluble | Electrode | PMS-05 | mg/kg | 2810 | 3030 | 1585 | 4.6 | 212 | 310 | 362 |
| Electrical Conductivity | Electrode | R&L 3A1 | dS/m | 1.93 | 2.1 | 1.86 | 0.02 | 0.3 | 0.54 | 0.36 |
| Total N (LECO) | LECO | R&L 7A5 | mg/kg | 13350 | 14590 | 6870 | 82.2 | 235 | 1624 | 1745 |
| Extractable Nitrate-N | H20/UV-Vis | PMS-08 | mg/kg | 50.7 | 52.9 | 2.34 | 4.4 | 4.28 | 10 | 9.4 |
| Organic Carbon (LECO) | LECO | R&L 6B3 | % | 32 | 36.5 | 5.9 | 0.11 | 0.4 | 3.11 | 2.01 |
| Total Carbon (LECO) | LECO | R&L 6B2a | % | 31.7 | 36.9 | 61.1 | 0.12 | 0.36 | 4.88 | 5.27 |
| Phosphorus Buffer Index | UV-Vis | PMS-12 | mg/kg | 127 | 136 | 460 | 20.7 | 43.5 | 37.5 | 21.5 |
| Phosphorus (Colwell) | Bicarb/UV-Vis | R&L 9B1 | mg/kg | 316 | 322 | 99.3 | 7.72 | 10.9 | 45.2 | 38 |
| ECEC | Calculation | PMS-15A1 | Cmol/kg | 72.7 | 74.4 | 26.6 | 1.32 | 3.72 | 14.89 | 16.2 |
| Ca/Mg Ratio | Calculation | PMS-15A1 | Cmol/kg | 4.4 | 4.2 | 17.8 | 6.92 | 3.56 | 8.18 | 5.24 |
| K/Mg Ratio | Calculation | PMS-15A1 | Cmol/kg | 1.97 | 2.04 | 6.29 | 0.30 | 0.67 | 4.94 | 0.87 |
| Air-dried Moisture | AS4419 | UoN | % | 27.80 | 33.29 | 9 | 2 | 8 | 10 | 13 |
| Moisture Holding Capacity | AS4419 | UoN | % | 66 | 62 | 52 | 19 | 22 | 33 | 33 |
| Bulk density | AS4419 | UoN | kg/m3 | 550 | 550 | 210 | 1520 | 1180 | 1100 | 1100 |
| Ksat | CLE | UoN | mm/hr | 720 | 1400 | 105 | 2100 | 840 | 840 | 840 |

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Analysis includes Effective Cation Exchange Capacity (ECEC) which measures the ability to hold on to contaminants and plant growth factors such as Phosphorous Buffer (Retention) Index and Cation Ratio analysis that support the "integrity of surface vegetation". ECEC of less than 5 is indicative of low soil fertility (Apal, 2014).

Particle size analysis (e.g. Figure A) is carried out for a number of purposes. With reactive organic media, retention time is a factor in treatment efficiency. The CORE Specification identifies a Hydraulic Conductivity ($K_{sat}$) of <300mm per hour. This figure is based on research results showing that this provides a retention time conducive to optimum treatment outcomes and prevents superfluous ponding. Table 1 shows identical $K_{sat}$ for CRCWSC and CORE specifications.

However one of the advantages of media engineering is that media formulations can be configured at various conductivities, either higher or lower than 300 mm per hour. Favourable pollutant removal results are observed for higher $K_{sat}$. For example some installations call for media for use with combined sewer and stormwater systems where quantity management is a factor and higher $K_{sat}$ is required. Validation system testing can identify performance at various rates of conductivity. Conductivity can also affect lifespan (see figure 3 pp8).

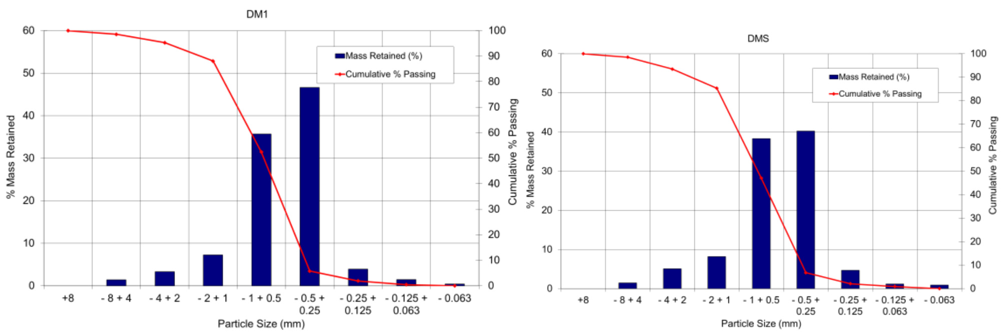


*Figure A - Typical PSD's of organic filter media*

## 2. PERFORMANCE

Table 2 identifies results from column leaching experiments showing removal performance using typical conservative stormwater pollutants. The table compares the removal of metals (Cu, Pb, Zn) by the CORE Specifications (RFM1 & 2) and FAWB/CRCWSC Specification. It should be noted that the results are based on reactive (chemical) processes without the influence of plant uptake or biological factors. Consequently the effect of vegetation and biology would be expected to yield higher removal results. Previous studies have been focussed on low organic soils so are not considered reliable indicators of effects on these factors from higher organic formulations. Future CORE field studies are being designed to quantify performance effects of improved vegetation integrity on treatment performance.

***Table 2 – Sample efficacy testing***

| Pollutant | Influent (µg/L) | Effluent | | | % Removal | | |
|---|---|---|---|---|---|---|---|
| | Stormwater | CRC/FAWB | RFM1 | RFM2 | CRC/FAWB | RFM1 | RFM2 |
| Copper | 162 | 4.2 | 7.2 | 6.4 | 97 | 96 | 96 |
| Lead | 0.4 | 0.4 | < 0.2 | < 0.2 | 0 | > 50 | > 50 |
| Zinc | 138 | 17 | 5 | 4 | 88 | 96 | 97 |

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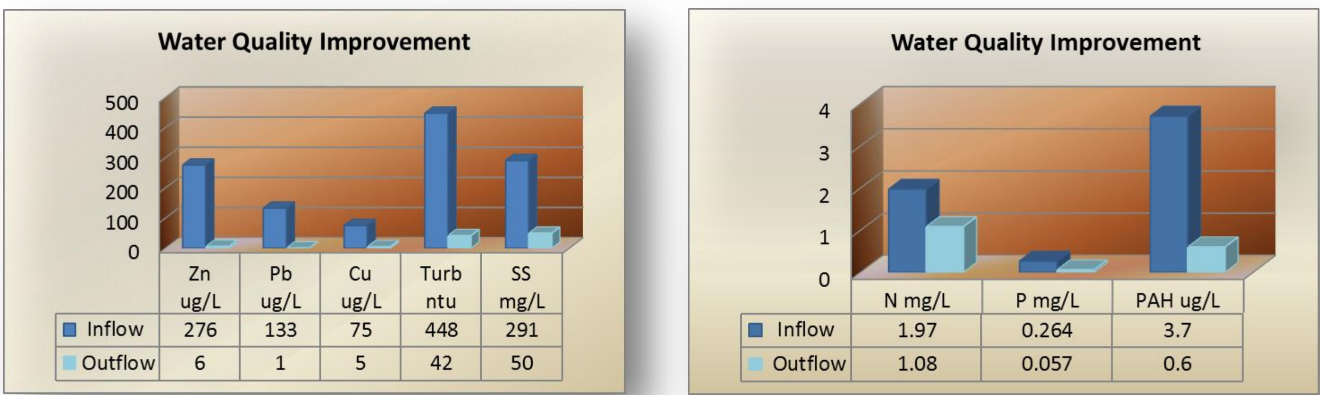
Figures 1 & 2 identify results over a range of common pollutants from an independent field study conducted by AWT (now Sydney Water) in early 1999. Note the high concentrations of metals and hydrocarbons which are not covered in many of the Australian treatment requirements or modelling programs.




***Figures 1 & 2 – Field results***

## 2.1 Performance modelling – TSS & Nutrients

The use of "look-up tables" in the Model for Urban Stormwater Improvement Conceptualisation (MUSIC) for bio-retention nodes is primarily based on the FAWB specification. This has created an algorithmic bias against high nutrient content material irrespective of its actual leaching behaviour. However using actual CORE Specifications performance data from reference formulations (RFM1, RFM2) produces reasonable treatment results. Nevertheless CORE Specifications performance is expected to be greater than that indicated in the MUSIC model.

The relationship between filter media Total Nitrogen and Orthophosphate content and treatment performance may be based on the inconclusive assumption that filter media with organic matter content ≤ 5 % leaches excessive nutrients. Examples in this report and studies by Al-Mashaqbeh, O., et al (2007) have demonstrated this is not necessarily the case. The following section elaborates and identifies how the CORE organic media Specifications can be modelled in MUSIC v6 to represent equivalent treatment performance compared to FAWB.

**From MUSIC v6:**

*"The selection of appropriate k and C* values for modelling the removal of Total Nitrogen cannot easily follow the procedure applied for TSS and TP. The composition of particulate and soluble forms of N in stormwater is highly varied. There is significantly smaller particulate fraction of TN compared with TP, and even that fraction is associated with organic particles which have significantly lower specific gravities than sediment. Calibrated k values for TN in wastewater systems indicate significantly lower values (as much as two orders of magnitude) compared with TP and TSS. The default k and C* values for TN are thus based on very limited data. There is an expectation that the k values are likely to be an order of magnitude lower than corresponding values for TP, and that the ratios of C* to inflow Event Mean Concentration (EMC) are likely to be higher for TN than for TP."*

Therefore, the nature of reference formulations comprising of 50% and 65% "organic matter" with an initial leaching peak that rapidly subsides back to stable levels, means that changes in k and C* need investigation. Selection of k and C* were based on Bio retention Systems (Table 5 in MUSIC, "Appendix G: Selecting Appropriate k and C* Values"). A simple sensitivity analysis was undertaken on three scenarios (changes in k and C*) and are described in Table 3 below. MUSIC v6 results (% reduction) are presented in Table 4.

***Table 3 - Changing k and C* in MUSIC v6 (sensitivity analysis inputs)***

| | TSS | | TP | | TN | |
|---|---|---|---|---|---|---|
| **Bio-retention Systems** | *K* | C* | *k* | C* | *K* | C* |
| LOW | 4,000 | 10 | 3,000 | 0.08 | 250 | 1.1 |
| Default | 8,000 | 20 | 6,000 | 0.13 | 500 | 1.4 |
| HIGH | 15,000 | 30 | 12,000 | 0.18 | 1,000 | 1.7 |

Sensitivity analysis shows that the FAWB Specification product was relatively unchanged with significant changes in k and C* and is likely a function of the fact that most research and development of the CRC Biofiltration Guidelines (Payne *et al*, 2015) have used sandy loam (FAWB) as their filter media. However, RFM1 and RFM2 (reference formulations) were highly sensitive to changes in k and C* with respect to TN (difference in treatment performance of 16.9 % and 19 % respectively). Results from this study have demonstrated that RFM1 and RFM2 are comparable filter media to FAWB in terms of pollutant removal and treatment performance yet this performance is not captured in MUSIC v6.

This is explained by the fact that the treatment performance data is governed by an extensive "lookup table", which determines outflow concentrations and/or removal rates for TSS, TP and TN and takes into account all important characteristics of the bio-retention system and its operating conditions. The "lookup tables" are based on extensive research and observations however the FAWB (sandy loam) Specification has been the preferred choice in most of the research over the past 10 years.

*Table 4 - Comparison using MUSIC modelling of pollutant treatment*

| | % Reduction | | | |
|---|---|---|---|---|
| **CRC/FAWB** | **LOW** | **Default** | **HIGH** | **Difference** |
| Flow (ML/yr) | 5.3 | 5.3 | 5.3 | 0 |
| Total Suspended Solids (kg/yr) | 94.5 | 95.8 | 96.5 | 2 |
| Total Phosphorus (kg/yr) | 90 | 90.5 | 90.6 | 0.6 |
| Total Nitrogen (kg/yr) | 72.3 | 72.7 | 73.1 | 0.8 |
| Gross Pollutants (kg/yr) | 100 | 100 | 100 | 0 |
| **RFM1** | **LOW** | **Default** | **HIGH** | **Difference** |
| Flow (ML/yr) | 5.3 | 5.3 | 5.3 | 0 |
| Total Suspended Solids (kg/yr) | 94.6 | 95.6 | 95.5 | 0.9 |
| Total Phosphorus (kg/yr) | 83.4 | 84.1 | 86 | 2.6 |
| Total Nitrogen (kg/yr) | 52.6 | 55.5 | 69.5 | 16.9 |
| Gross Pollutants (kg/yr) | 100 | 100 | 100 | 0 |
| **RFM2** | **LOW** | **Default** | **HIGH** | **Difference** |
| Flow (ML/yr) | 5.3 | 5.3 | 5.3 | 0 |
| Total Suspended Solids (kg/yr) | 94.2 | 95.3 | 95.6 | 1.4 |
| Total Phosphorus (kg/yr) | 77.3 | 77.9 | 79.7 | 2.4 |
| Total Nitrogen (kg/yr) | 47.6 | 50.2 | 66.6 | 19 |
| Gross Pollutants (kg/yr) | 100 | 100 | 100 | 0 |

The "engineered" filter media RFM1 and RFM2 do not contain significant silt/clay content, as the exchange capacity is provided by the selected organic matter (higher ECEC, refer Table 1). Therefore, future study may look to develop "lookup tables" suited to the use of CORE Specifications materials, such as RFM1 and RFM2, by monitoring flow and water quality (inflow and outflow) of "real-life" raingardens. Furthermore, since RFM1 and RFM2 behave similarly to the FAWB Specification products with respect to nutrient leaching (figure 4) and pollutant removal it makes sense to use similar "inputs" to MUSIC v6 for RFM1 and RFM2, i.e., the same values one would use for FAWB.

### Treatment Node:

As a result of the equivalent leaching behaviour with FAWB/ CRCWSC and CORE Specifications the "TN Content of Filter Media" in MUSIC's Treatment Node "Filter and media properties" variable is to be input at 235 mg/kg (Table 1).

## 2.2 Performance modelling - Metals

Maintenance is a key factor in any bio-filtration system. Figure 3 is a screen shot of one page from CORE's computer model (Kalkulus™) specifically developed to calculate metals removal and media life span. UoN studies identify that Metals (conservative pollutants), not nutrients, determine the life span of a media.

**Figure 3 – Sample "Kalkulus"™ modelling of conservative pollutant removal and lifespan.**

| Step | COPPER (Cu) | | RFM1 | RFM2 |
|---|---|---|---|---|
| 1 | mg per 150 g | removed by DM | 7.49 | 7.47 |
| 2 | mg/kg | removed by DM | 50 | 50 |
| 3 | mg/L/m2 | in runoff | 0.25 | |
| | | | | |
| | **Raingarden example** | | | |
| 4 | Area (m2) | 100 | | |
| 5 | Depth (m) | 0.5 | | |
| 6 | Volume (m3) | 50 | | |
| 7 | BD (kg/m3) | 1,100 | | |
| 8 | Mass (kg) | 55,000 | | |
| 9 | Available Cu Store (mg) | | 2,747,800 | 2,739,367 |
| | | | | |

| | | | | |
|---|---|---|---|---|
| | **Catchment Characteristics** | | | |
| 10 | Rainfall (mm/yr) | 650 | | |
| 11 | Catchment area (m2) | 1,000 | | |
| 12 | Volume of Runoff (L/yr) | 650,000 | | |
| 13 | Cu load (mg/yr) | 162,500 | | |
| 14 | Life Span (yrs) | | 16.9 | 16.9 |
| | Enter data into light blue cells | | | |
| | | includes "Compaction Factor" | | |
| | | (relates to Mass) | | |
| | | 1500 mm/hr | 10.1 | 10.1 |
| | | 1100 mm/hr | 13.8 | 13.8 |
| | **Test condition** | 900 mm/hr | 16.9 | 16.9 |
| | | 850 mm/hr | 17.9 | 17.8 |
| | | 800 mm/hr | 19.0 | 19.0 |
| | | 750 mm/hr | 20.3 | 20.2 |
| | | 450 mm/hr | 23.7 | 23.6 |
| | **Test condition** | 300 mm/hr | 25.4 | 25.3 |
| | | 100 mm/hr | 28.7 | 28.7 |

Data from the component and Filter Media formulation testing is used to calculate filter size or alternatively calculate the lifespan where only a certain footprint size can be installed.

You will notice that with the CORE Specifications lifespan can be increased by longer retention time using compaction.

This model is currently under further development as a specification design aid, enabled by funding contributions from the Commonwealth Government.

## 2.3 Performance modelling – Leaching

Figure 4 shows results from UoN leaching studies of components (RO Cat 1, 2 &3) and reference formulations (FAWB, RFM1 & RFM2). The CORE Specification reference formulisations exhibit “acceptably low leaching” of reference formulations (RFM1& RFM2), compared to M165 (FAWB/CRCWSC) and both stabilise relatively quickly.

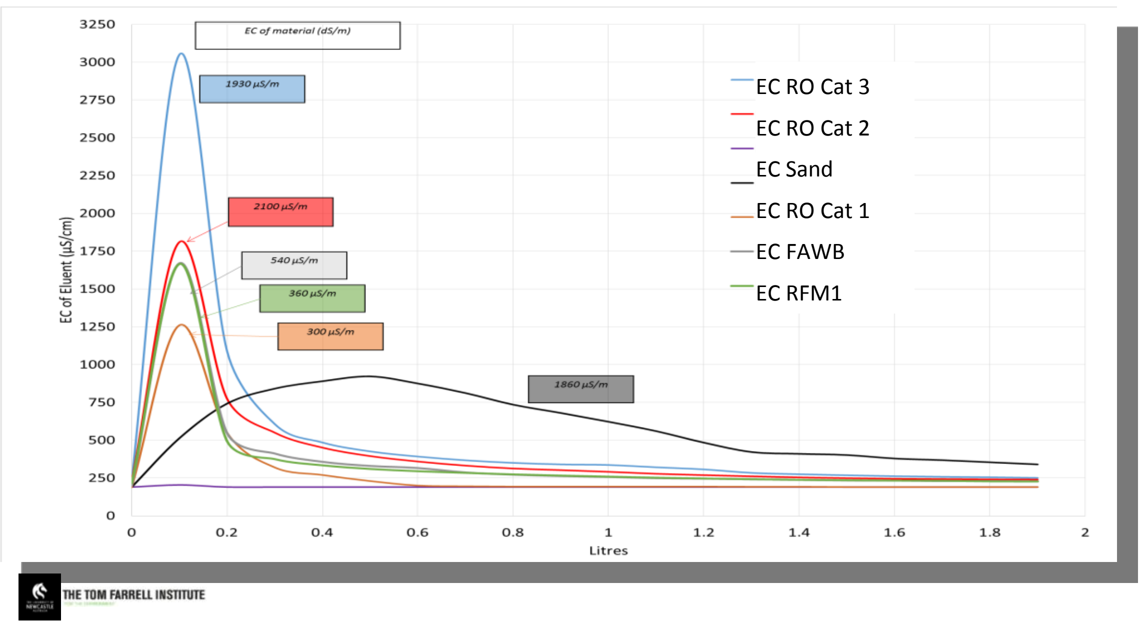



***Figure 4 – Sample comparison of leaching behaviour***

Tap water eluted through all materials results in leaching of cation/anions (as increasing EC). However all materials, except washed sand and RO Cat 1, produce a relatively high peak before returning near to initial tap water EC (at around 1.4 L). Washed sand did not produce a peak (low ECEC, no cations/anions to be leached). RO Cat 1 displayed a longer wetting time, hence the broadness of the "peak" before trending back to tap water EC values (250 µS/cm).

Due to low wettability properties it takes time for the RO Cat 1 to become fully wetted and start leaching salts, and the leaching curve (Figure 4) exhibits that delay. Due to the relatively low $K_{sat}$ (105 mm/hr, see Table 2), RO Cat 1 did not leach all exchangeable cations/anions over 2 L of tap water application. This material has other valuable properties (refer table1) that contribute to performance efficiency. These factors determine the variable proportions used in engineering media formulations for specific systems.

Washed sand had a low ECEC (1.32 Cmol/kg, refer Table 1) therefore had minimal leaching (see Figure 4). Washed sand had the highest $K_{sat}$ indicating the lowest residence time however potential exchange sites for pollutant removal are very low (low ECEC).

The difference in the EC peak between RO Cat 1 & RO Cat 2) was due to $K_{sat}$, where the RO Cat 1 had a lower $K_{sat}$, hence a longer residence time, which resulted in a higher leaching peak (Figure 4). Both RO Cat materials had the highest ECEC (~ 73 Cmol/kg, refer Table 2) indicating their ability to remove pollutants.

FAWB (M165), RFM1 and RFM2 all had similar $K_{sat}$ values (similar residence time in the columns) however RFM1 and RFM2 both have significantly more exchange sites than FAWB for pollutant removal (higher ECEC). The higher leaching peak for RFM1 and RFM2 rapidly subsided and after 2 L of tap water and the EC of the eluted tap water was similar to FAWB at the same stage.

Change in pH is shown in Figure 5. ANZECC (2000) guideline trigger values for aquatic ecosystems (SE Australia) range from 6.5 – 8.5 and all materials achieved this except component material RO Cat 1 (high pH). Results indicate that discharge from use in engineered formulations, from a raingarden for example, would be within the desired pH range.

RFM 2 reference formulation has an organic content of 65%. This was used for experimental design purposes and is not expected to be used in field formulations. However it is interesting to note pH and leaching remained within acceptable parameters (ANZECC) even at this high level of organic content.

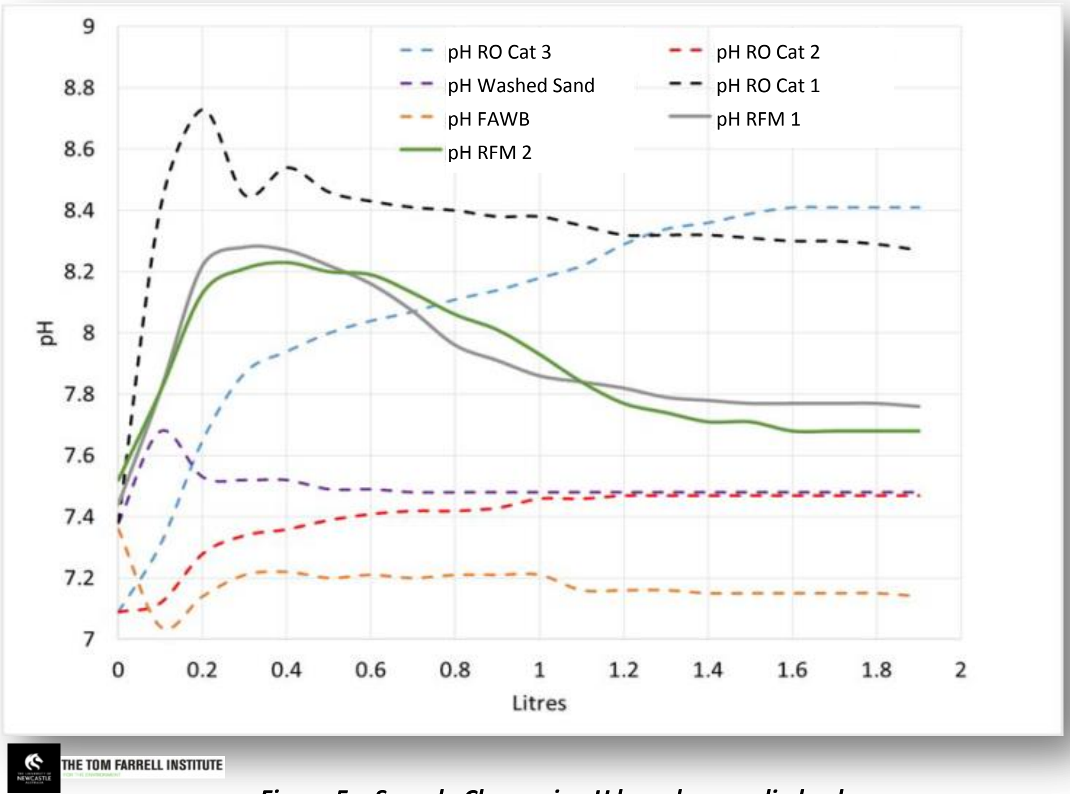



***Figure 5 – Sample Change in pH based on applied volume***

Research undertaken by McLaughlan (2008) also demonstrated the contaminant leaching of recycled organics and concluded:

1. Long term studies have shown that the level of inorganic nitrogen released from recycled organics amendment is similar or less than soil;
2. Continuous flushing of the recycled organics amendment with water caused leaching of nitrogen, phosphorous and carbon however the rate of leaching declined rapidly to stable values;
3. The amount of nutrients released from stormwater treatment devices using recycled organics amendment is expected to be under the limits required for agricultural application and national water quality guidelines.

## 3. SUMMARY OF MATERIALS ANALYSIS

Table 4 summarises results of organic and non-organic components and media formulations. This section also includes an analysis of comparative results.

***Table 4 – Summary of comparative analysis***

| | CRC Biofiltration Objective | RO-Cat 3 | RO-Cat 2 | RO-Cat 1 | Washed Sand | M165 | RFM1 | RFM2 |
|---|---|---|---|---|---|---|---|---|
| Material | Engineered soil/sand | NA | NA | NA | √ | √ | √ | √ |
| Hydraulic Conductivity | 100 - 300 mm/hr | √ | √ | √ | √ | √ | √ | √ |
| Clay & Silt content | < 3% | √ | √ | √ | √ | √ | √ | √ |
| Grading of particles | 0.05 - 3.4 mm sieve size | NA | NA | NA | √ | √ | √ | √ |
| Nutrient content | TN < 1000 mg/kg | 13350 | 14590 | 6870 | **82** | **235** | 1624 | 1745 |
| | Extractable Nitrate (No limit?) | 50.7 | 52.9 | 2.34 | 4.4 | 4.28 | 10 | 9.4 |
| | Available P (Colwell) < 80 mg/kg | 316 | 322 | 99 | **8** | **11** | **45** | **38** |
| Organic matter | Minimum content ≤ 5% | 100 | 100 | 100 | 0.1 | 0.4 | 40 | 50 |
| Organic carbon | ? | 32 | 36.5 | 5.9 | 0.11 | 0.4 | 3.11 | 2.01 |
| Total carbon | ? | 31.7 | 36.9 | 61.1 | 0.12 | 0.36 | 4.88 | 5.27 |
| pH (1:5 in $H_2O$) | 5.5 - 7.5 | 7.76 | 7.87 | 9.23 | 7.72 | **6.80** | 8.29 | 7.74 |
| Electrical Conductivity | < 1.2 dS/m | 1.93 | 2.1 | 1.86 | **0.02** | **0.3** | **0.54** | **0.36** |
| Horticultural suitability | To be assessed by horticulturist | NA | NA | NA | NA | √ | √ | √ |
| Particle Size Distribution | fine sand (10-30%) | NA | NA | NA | √ | √ | √ | √ |
| Depth | 400 - 600 mm or deeper | NA | NA | NA | √ | √ | √ | √ |
| Once-off nutrient amelioration | Added to top 100 mm | NA | NA | NA | Yes | Yes | No | No |
| Submerged Zone | High HC or shallow depth | NA | NA | NA | √ | √ | √ | √ |

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***Material***

RO (Cat 1, 2 & 3) are component materials and consequently are not considered as engineered media. Washed sand, M165/FAWB, RFM1 and RFM2 (Reference Formulation Media) can be considered as engineered media and satisfy CRC Guideline requirements.

***Hydraulic Conductivity***

All materials can be compacted to achieve desired hydraulic conductivity. A formulation based on RFM1 was tested under BS1377 (Part 5) which resulted in a saturated hydraulic conductivity ($K_{sat}$) of < 300 mm/hr. This level is used in the CORE Specification and is also within the CRCWSC Guideline requirements.

***Clay and silt content***

All materials contained < 3 % clay content and satisfy CRC Guideline requirements. The CORE Specification cites Emerson class 8 which signifies no dispersion.

***Grading of particles***

RO Cat 1, 2 & 3 (components) have a wider (and higher) range of particle sizes that exceeded CRCWSC Guideline requirements. Greater than 95 % of particle sizes in the washed sand, FAWB, RFM1 and RFM2 (formulations) were within Guidelines (0.05 – 3.4 mm) and are considered satisfactory for use in raingardens.

***Nutrient content***

RO Cat 1, 2 & 3 (components) contain TN that far exceeds CRC Guideline requirements (> 1000 mg/kg). Washed sand and /FAWB are well below the CRCWSC Guideline requirement and, since this can be too low to sustain plant growth, potassium nitrate and superphosphate are suggested additives to FAWB (at 300g/m3). RFM1 and RFM2 (formulations) exceeded the CRCWSC Guideline requirement however the values modelled in MUSIC v6 in Table 4 demonstrate the suitability of RFM1 and RFM2 as filter media in raingardens. RO Cat 1, 2 & 3 contain orthophosphate (plant-available phosphorous as Colwell P in Table 2) that exceeds CRCWSC Guideline requirements (< 80 mg/kg). Washed sand, FAWB, RO Cat 1 & 2 were all within Guidelines. Inherent "exchangeable" nutrient content in the materials can assist in providing valuable nutrients during plant establishment and growth and avoid the use of chemical fertilisers.

***Organic matter***

RO Cat 1, 2 & 3 (components) are all 100% organic matter and do not satisfy CRCWSC Guideline requirements. RFM1 and RFM2 (formulations) were 50% and 65% organic matter respectively and washed sand and FAWB had minimal organic matter (0.1 % and 0.4 % respectively). This requirement (≤ 5 % organic matter) has been the subject of contention due to claims of excess leaching of nutrients. However it has recently been acknowledged that this not always correct:

*"There may be soil with higher organic content that the level specified that may not leach nutrients (TN and/or TP). It is also acknowledged that organic matter content does not have a direct link to nutrient leaching." – CRCWSC, 2015.*

***pH (1:5 in water)***

The pH values in the CRCWSC Guidelines essential specifications prescribe a value of 5.5 to 7.5. The RFM materials ranged from 6.8 (FAWB) to 9.2 (RO Cat 1). It should be noted that pH of components can be buffered by adjusting media formulations accordingly or adding materials with pH buffering characteristics (e.g. calcium) if required. The pH is within ANZECC guidelines for both organic media *reference formulations (RFM1 & 2).

***Electrical conductivity (EC, 1:5 in water)***

RO Cat 1, 2 & 3 (components) exceeded CRC guideline values (> 1.2 dS/m). Washed sand, FAWB, RFM1 and RFM2 were within CRCWSC Guidelines (< 1.2 dS/m) and are considered satisfactory for use in raingardens.

***Horticultural suitability***

RFM1 and RFM2 (formulations) have been deemed as appropriate for use in raingardens based on the data in Table 1. Note that the FAWB Specification allows for an initial addition of fertilizer at a rate of 300 g/m$^3$ to compensate for the low inherent nutrient levels. Horticultural ratios are included in the CORE Specification to describe media characteristics that are considered important during growth and development of vegetation.

***Particle size distribution***

The CRCWSC Guideline states that the filter media should be 10–30% fine sand. FAWB, RFM1 and RFM2 ranged between 30 – 35% fine sand and satisfy CRC Guideline requirements. Final mixes for RFM1 and RFM2 have particles over the size range prescribed in the CRC Guidelines. However no negative performance consequences are identified.

***Depth***

Washed sand, FAWB, RFM1 and RFM2 can be used for the CRC Guideline requirement for depth.

***Once-off nutrient amelioration***

Not required for RFM1 and RFM2 however FAWB may need amelioration.

***Submerged zone***

Washed sand, FAWB, RFM1 and RFM2 can be engineered to increase or decrease hydraulic conductivity (depending on compaction) to satisfy the CRC Guideline requirement.

***Conclusions***

The design mix formulations RFM1 and RFM2 appear to be an acceptable comparable media to FAWB for use in raingardens.

Data presented in this report supports the CRCWSC's acknowledgment that "*higher organics content than the level specified (in the FAWB /CRC guidelines) don't necessarily leach nutrients (TN and or TP). It is also acknowledged that organic matter content does not always have a direct link to nutrient leaching"- Tony Wong CRCWSC.*

The nutrient content of the CORE Specifications component materials can eliminate the need for application of fertilisers and/or mulches for plant establishment. The horticultural properties of the CORE Specifications also enable a wider range of plant species to be grown. This includes local species resulting in lower maintenance cost and enhanced plant health and survival.

The media system methods and customisation capabilities of the CORE Specifications enable engineering of component formulations to achieve the performance objectives of the applicable systems. This includes varying hydraulic conductivity to accommodate wide-ranging flow rate variations for high and low flow performance requirements. Previous studies (McLauglin et al, 2008) show no deterioration in conductivity over a (simulated) 30 year period in organic media.

## 4. QUALITY ASSURANCE

QA is considered more than just producing a test certificate showing media compliance with physical properties. CORE Specifications (attached) are validated consistent with research findings and Australian Standards Guidelines (AS4454, AS 4419). Strict Manufacturing QA guidelines are inspected as part of the validation process to ensure consistent performance. Consequently statutory warranties can be provided by manufacturers. Operational Specifications are also developed for usage and installation but are generally consistent with CRC/FAWB guidelines.

## 5. INTEGRITY OF SURFACE VEGETATION COMMUNITY

CRCWSC acknowledgement of the suitability of other media systems states that in addition to hydraulic and leaching behaviour a media system must ensure the "integrity of surface vegetation community". Organic media meeting the CORE Specifications are a new generation of media that achieve best practice pollutant removal and exhibit advantageous plant growth properties. Leaching composition shows beneficial properties for plant establishment.

The CORE Specifications organic media has inherent system properties specifically designed for vegetation health resulting in improved establishment and longevity outcomes while lowering maintenance requirements. The intrinsic horticultural properties also enable a far wider variety of vegetation and plant species to be utilised including plants indigenous to specific geographical jurisdictions. This improves plant viability and lower attrition reduces maintenance costs.

The CORE Specification organic media increases the integrity of plant establishment, growth and phytoremediation through increased root mass development. Figure 6 shows the larger root mass of a plant grown in an organic media compared to the root growth in a nonorganic soil. Larger root mass can facilitate improved pollutant removal and healthier, more resilient vegetation.

***Figure 6 - Comparison of root development in organic and non-organic formulations***

The following pictures show some examples of surface vegetation plant growth using the CORE Specifications.

***Pictures – Examples of vegetation integrity using organic media***

**Kerbside garden**

**Bio Retention Basin**

**Harbour side Car Park**

**Annexure 1**

# Specification LGE01

# Landscape Filter Media

**DESCRIPTION:**

Purpose designed for specific landscape, detention basin and rain garden applications, Landscape Filter Media allows for the efficient infiltration and treatment of contaminated water run-off from roads, car parks and other impermeable surfaces. The treated water can then be stored and re-used for fit for purpose use such as landscaped areas irrigation. A wide range of plant species and vegetation can be grown in Landscape Filter Media due to the high water retention capacity, organic content and the material nutrient characteristics.

The following specifications are to be used in combination with accredited formulation technology to achieve specific performance requirements. Filter formulations can be purpose designed based on factors such as treatment requirements, hydrology, device, application and plant species used. Product mixtures are to contain CORE accredited components which may include zeolite, recycled carbon materials, perlite, zero valent iron, ash, sawdust, recycled organics, limestone and microbial inoculants and can also be produced in various grades and mixtures for transition and drainage layers. Compaction, particle size selection and other properties can be engineered to achieve specific hydraulic conductivity, life span and retention time requirements.

***Specification for Landscape Filter Media LGE012***

| | |
|---|---|
| Hydraulic Conductivity ($K_{sat}$) | a. < 300mm/hr (compacted to AS1289.6.7.2 - 2001)<br>b. < 900mm/hr (uncompacted) |
| pH (1:5 in $H_2O$) | 6.5 to 8.0 |
| Organic Carbon | $\leq$ 5% |
| Wettability | < 5mm/m (AS4454) |
| Effective Cation Exchange Capacity | > 10 cmol/kg |
| Moisture content (air dried) | > 10% < 50% |
| Inherent Retention Capacity | > 25% |
| Toxicity | > 60mm (AS4454) |
| EC | < 1 dS/m (AS4454) |
| Dispersion | Emerson Class No 8 |
| Leaching | EC < 300 µS/cm after 350mm rainfall |
| Ponding | Water fully drained from media in 6 hours |
| Vegetation integrity | a. Ca/Mg ratio $\geq$ 2:1<br>b. K/Mg ratio $\leq$ 1.5:1 |

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## Annexure 2

Other CORE Specifications:

- Pavement (non-structural grade)
- Pavement I(structural grade)
- Retaining Wall
- Roof Garden  (Standard Weight)
- Roof Garden (Light Weight)
- Planter Box
- Sports Field  (Standard Formulation)
- Sports Field  (High Performance)
- Golf Course
- Race Track
- Leach Drain/ Industrial

## Annexure 3

# Synopsis of validation methodologies.

**Materials and Methods**

The validation report is a culmination of research results from fundamental and original studies over a 10 year period. The production of cogent data has often required the development of new and adapted research methodologies, material characterisation processes and classification systems many of which are now covered under international patents. Experimental designs are based on simulating natural soil mechanisms and hydraulic processes to achieve specific performance outcomes. In the interests of sustainable procurement, preference is always given to studies of promising recycled materials.

Special acknowledgment is given to fundamental, independent research studies conducted by UTS, UNSW and Melbourne University (McLaughlan, 2006 - 2008) and original work by University of Newcastle (Lucas, *et al, 2012-2016*). This section is designed as a synopsis of the main methods and types of materials that apply to the data presented in this report, and are used in the ongoing research programs and validation processes. Several papers (*op cit*) have been written and published that can provide more detail if of interest.

**Materials**

CORE Research has already identified and classified a wide range of potential materials that could be used as components in an organic and non-organic bio-filtration filter media formulation. Materials could include organic and mineral materials including zeolite, activated carbon, selective recycled carbon materials, aggregates, clay, perlite, zero valent iron, limestone, pumice, forest residues, sawdust, peat, basalt, sand, recycled glass, titanate, soil & other reactive materials. Each component material validated by CORE is tested and classified according to its individual characteristics and efficacy in achieving the desired functional requirements when these materials are combined into performance based formulations. An international data bank of materials characteristics is established and growing.

**Batch tests**

Batch tests are designed and used to identify the efficacy of prospective materials that could potentially be used in bio filter formulations. Batch test are generally conducted at a solid to liquid ration of 1:5 based on previous studies. Selected stormwater runoff, industrial waste water and secondary treated effluent (STE) are used as the liquid solutions and are chosen depending on the objective of the experiments. For example STE and industrial waste water better enable removal results to be more clearly identified and measured for higher pollutant concentrations compared to the lower contaminant concentrations in stormwater. Batch tests can be carried out on a number of materials at once and can quickly measure relative efficacy results at a lower cost and contribute to identifying poor performing materials that can be ruled out prior to more extensive testing.

**Column tests**

Once suitable components are identified, indicative reference formulations media are designed. Column studies are carried out on component materials and reference formulations under constant-head and falling-head conditions to establish performance characteristics. Reference formulations include combinations of organic and mineral materials that are formulated based on batch test results, classification data, judgmental selection and/or snowball design. The reference formulations are designed based on characteristics that would satisfy general requirements such as hydraulic conductivity and pollutant removal performance.

The column studies are generally designed under different hydraulic head conditions (constant and falling) to investigate the likely *in-situ* performance of the engineered media. For example, column tests are an open system test that indicate how a reference formulations would behave under high flow conditions (saturated, low residence time) and low flow conditions (un-saturated, high residence time).

Packing of the columns is based on volume. For each material or formulation, a column is packed with a known volume of reference formulation and the height in the column is measured. Each column is gently tapped and shaken to promote settling but no compaction is applied (except during retention studies). Column depth is then measured. The appropriate test solution is then selected for the column tests.

From the unfiltered eluted sample emerging from the column, pH and electrical conductivity (EC, µS/cm) is carried out using a calibrated Horiba pH/EC meter. Nutrient analysis includes Total Kjeldahl Nitrogen (TKN), Total Oxidisable Nitrogen (TON), Total Phosphorous (TP), Total Nitrogen (calculated as TKN + TON). Metals analysis comprised of at least Ca, Na, Mg, K, Cu, Pb, Zn and Cd.  Total Suspended Solids (TSS) and Total Petroleum Hydrocarbons (TPH) are also studied.

For constant-head conditions, a measured volumetric flask containing the selected liquid is slowly poured into the top of the column. There is a point where the top of the column contains a "head" and at this time the volumetric flask is quickly inverted and the spout submerged in the liquid above the reference formulations in the column. The volumetric flask is clamped in place and the liquid moves through the column under gravity.

The time taken for the liquid to be eluted through the column reflects the saturated hydraulic conductivity ($K_{sat}$) of the reference formulation and is determined by calculation (volume/time). The measured volume of liquid is applied under constant-head conditions to measure the equivalent millimetres of a rainfall event. For example, 1L/ $m^2$ = 1 mm rainfall depth and since the area of the column and applied liquid volume is known, an equivalent rainfall depth can be calculated. If the area of a column is 0.00238 $m^2$ ($A = \pi r^2$) then 1L of liquid applied is equivalent to 420 mm of rainfall (1L / 0.00238 $m^2$). If 1L takes 1 hour to move through the column, then the $K_{sat}$ would be 420 mm/hr.

After elution, any losses from the liquid are deemed to reflect the inherent moisture retention capacity (MRC) of the reference formulations and is calculated using mass by difference. For example, if 1L of liquid goes into the column and 0.8L is eluted out of the column (when freely drained), then the MRC equals 20 %.

For the falling-head column tests on  a reference formulation the liquid is placed in a measured reservoir with a small tap fitted with a slow-release valve that allows the liquid to drip into the column rather than flow freely under constant-head conditions. The reason for the falling-head column test is to better mimic low and/or intermittent rainfall conditions and increase residence time of the liquid in selected reference formulations.

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