Investigating Stormwater Filters and Bioretention Systems

A Study on the Filterra(TM) and Up-Flo(TM) Systems Manufactured by Hydro-International

G1 Group Report

Supervisor: Dr Gavin Tabor

Group Members:

Alastair Begley
Stephen Pavey
James Please
James Ronald
Suzanne Russell
Jon Tarrant
Louisa Whitehurst
Stevie Winston-Gore

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Section I - Project Overview

1. Introduction

1.1 The Need for Stormwater Management

Stormwater management is an important aspect of controlling urban water systems. Increasingly restrictive legislation regarding water cleanliness and the growing focus on the environment in the wider culture are driving factors for the design of stormwater management systems. These dynamics are constantly demanding increasing levels of pollutants to be removed.

In particular the Water Framework Directive (WFD) was adopted by the EU in October 2000. This requires surface-water management across Europe to meet quantified cleanliness criteria, aiming to bring a greater focus on environmental considerations. This was introduced to UK law in 2003.

To purify wastewater, both large and small scale pollutants need to be removed. In urban areas water becomes polluted with many different elements including chemical and particulate matter. Traditionally, this wastewater has been cleaned in large scale processing plants at the end of the sewerage system. These processes consume significant amounts of energy and generate high volumes of bio-solids. It is however possible to clean the surface run-off using many smaller-scale biological and / or mechanical processes including bioretention systems at the point of entry to the system. This eases the workload on water treatment plants.

The wide-scale implementation of such systems will increase when the Sustainable Urban Drainage Systems (SUDS) legislation is introduced to the UK in 2012. This law will increase the focus on using natural systems for water cleaning at the beginning stages of the sewerage network. Such designs do not require energy input from the national grid, reduce the pressure on the existing infrastructure, minimises incidence of flooding and can be aesthetically pleasing.

1.2 Bioretention Systems

Bioretention systems comprise of different grades of porous filter media and the use of biological processes to clean chemical pollutants from the water while regulating the flow. The stormwater is diverted into the system, where it filters through a soil bed. Pollutants are removed both by this filtration process and the fluid uptake of the root system.

The removal rate depends on the choice of vegetation and the depth and porosity of the soil bed. The combined processes can be designed to remove around 85% of pollutants[1] including oils, nutrients, suspended solids and bacteria. A prominent example of such a design is the *Hydro Filterra* system, produced by *Hydro International.*

1.3 Company Profile: *Hydro International*

Hydro International was formed in 1980. It specialises in products for the cost effective control of stormwater and treatment of wastewater[2]. It aims to develop new technologies that treat

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[1] http://www.nj.gov/dep/stormwater/bmp_manual/NJ_SWBMP_9.1%20print.pdf
[2] http://www.hydro-international.biz/index_uk.php

stormwater and control surface runoff at the initial stages of the sewerage network. Once designed and installed *Hydro International* also offers maintenance contracts.

Hydro Filterra was developed by *Hydro International* in conjunction with the University of Virginia's Civil Engineering Department. More than 4,000 units have been installed within the USA[3], establishing the design as a major competitor in the sustainable water treatment market and was recently introduced into the UK.

1.4 The *Hydro Filterra* Bioretention system

Hydro Filterra has significant advantages over other designs. This bioretention system uses a unique, specially engineered soil which ensures consistent performance across all installations. This soil is located between a mulch layer with energy dissipating stones and gravel layer below as shown in **figure 1.** This design differs from other bioretention systems which have differing soil properties depending on location. The homogeneity of *Hydro Filterra* installations makes it easy to specify the design for individual installations resulting in an above average performance across the fleet. The combined function of each design element allows both large and small scale contaminants to be removed.

Despite the small size of the unit, which makes it easy to install, it still removes sufficient levels of pollutants to satisfy WFD and SUDS. The precise size of the unit is worked out based on the needs of the client. On top of this design flexibility, there are many species of vegetation which can be used in this system, all of which have been tested for their pollutant removal rates.

These removal rates which have been independently verified by various 3rd parties including the Technology Acceptance Reciprocity Partnership (TARP) involving laboratory work and 12 months extensive research in the field.

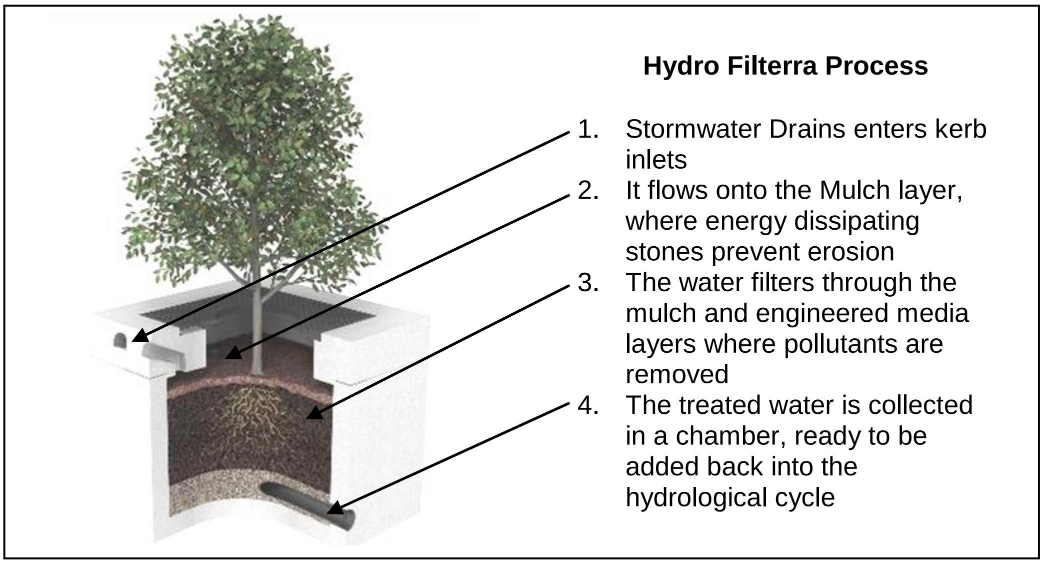

Figure 1 - Hydro Filterra Bioretention System [4]

[3] http://www.hydro-international.biz/media/Filterra%20Design%20Manual%20A0611.pdf
[4] http://cms.esi.info/Media/productImages/28683_1313421457846_PF.jpg

2. Project Definition

In this project, the wastewater filtration processes and hydrodynamic flow through the filter media will be investigated using both laboratory and computational methods. The overall aim is to determine the flow parameters for the *Hydro Filterra* system, the results of which are to be delivered to *Hydro International.*

All analysis will be conducted for a single case study installation. The micro level CFD, including soil and root analysis, built using micro-CT scans of the media, will provide the flow coefficients which will be used to construct the macro level CFD models. This data will be verified experimentally using macro tests on soil samples and using rapid prototyping. The latter is to analyse the soil on a micro level using fluid tests. Data from the case study will be obtained from *Hydro International* for further comparison.

The results from both the micro CFD and experiments will be used to calibrate a large-scale numerical model of the wider sewerage system. This will be used to compare the results of both methods and then to analyse the network with and without the *Hydro Filterra* units. Final soil properties will be used to build a macro scale CFD model of the system from the runoff level to the outflow into the sewer network. Optimisation of inlet flows and casing structure will also be completed. Potential extensions include extensive research into the effects of root growth, product lifecycle, specification of an ideal filter media and sewer network integration.

3. Project Management

3.1 Group Overview

The group consists of a mixture of Mechanical and Civil Engineers, each with different specialities and experience. The first meeting was held on the 4th October 2011 where ideas were discussed. This yielded a natural specialism divide between experimental and Computational Fluid Dynamics (CFD) approaches.

Within the identified sub-groups, the project was further broken down into macro and micro scale investigations. These areas were researched to decide upon individual tasks. Each member specified their project with work packages, the sum of which formed a basis for the project. These were chosen with respect to the other tasks, allowing for flow of information and deliverables. An overview of this flow is shown in the Gantt chart on **page 10** which indicates the project time line and critical path. Completion dates for individual aims are identified, along with the required flow of information between team members.

3.2 Group Meetings

3.2.1 Formal Group Meeting

Weekly group meetings were scheduled from the 4th October 2011 and are observed by Dr Gavin Tabor, the group supervisor. It was decided to rotate the roles of chair and secretary in order to spread the workload and allow each group member the opportunity to gain experience and develop leadership skills in a formal working environment. To this end agendas are proposed prior to the meeting and minutes are reviewed via an online forum detailed in **section 3.3**. In each meeting the secretary is elected for the following week and subsequently becomes the chair the week after.

3.2.2 Subgroup Meetings

Separate subgroup meetings also occur weekly, giving each team member the opportunity to discuss their individual work. Some individual projects coincide with others and these meetings allow team members to discuss the overlapping areas. The slightly more informal atmosphere allows the opportunity for group members to deal with minor obstacles before bringing more significant issues to the formal full group meeting where they can be discussed and recorded.

3.3 Online Forum

A secure online forum[5] has been set up in order to allow fast and easy communication amongst the whole group. The meeting agenda and minutes are uploaded in a section on the forum along with a library that allows members to share useful resources. Members will highlight particular parts that may be of interest to the group, further sharing the workload. There are separate CFD and practical discussion pages along with a whole group discussion page.

3.4 Team Roles

Three further roles have been identified; namely a Treasurer and the Company Liaison Officer (CLO). The former is tasked with handling the finances of the group, taking responsibility for the £640 budget. This role was allocated to Louisa Whitehurst since her role (specified in **section II**) is within the experimental group where the majority of the expenditure is anticipated.

The CLO was allocated to regulate communication with *Hydro-International,* in order to ensure a professional relationship between the group and the company. James Please was elected for this position, relaying communication records through meetings and the forum. It was decided that the rotation of chair person superseded the need for a team leader, although Jon Tarrant was identified as project co-ordinator to serve as a main point of contact for the group. The individual project areas are outlined in **table 1** and outlined in detail in **section 2.**

Member	Task
Alastair Begley	Three Dimensional Image Based Meshing and Computational Analysis of Fluid Flow in Various Porous Media
Stephen Pavey	Macro Scale Computational Analysis of Filtration inside *Hydro Filterra Drainage System* including Porous Media and Free Surface Interactions
James Please	Micro Scale Experimental Investigation to Determine the Hydraulic Properties of the Hydro Filterra Bioretention System with Comparison to tests on a Rapid-Prototype Sample and Computer Model Based on the Micro-CT Scans
James Ronald	Computational Modelling Of Plant Root Architecture and Fluid Absorption through Filtration Media Populated By Root Structures
Suzanne Russell	. Finite Element Analysis and Optimisation Investigation into the Chamber and Protective Grate used as part of the Bioretention System
Jon Tarrant	Macro Scale Computational Analysis of the *Hydro Filterra* Stormwater Drainage System in an Industrial Urban Environment
Louisa Whitehurst	Macro Scale Experimental Investigation to Determine the Hydraulic Properties of the Hydro Filterra Bioretention System with Comparison to the Hydraulic Performance of the Case Study
Stevie Winston-Gore	Investigating the Wide Scale Impact of Integrating a *Hydro Filterra* Bioretention System within an Urban Drainage Network Using Computational Models

Table 1 – Individual Project Titles

[5] mp-p.co.uk/other/project

Section II - Individual Goals

This section outlines in detail the individual tasks within the group. Firstly the work to be completed by the experimental team is described. The interaction of the *Hydro Filterra* system with the sewerage network is outlined. This is followed by the two experimental sections. Finally the construction analysis of the casing is specified.

Next the CFD group roles are outlined. These are described starting with the micro scale analysis, which provides the parameters used in all other models. This micro scale work is extended by the study of the root system, with the two macro scale CFD models described last, starting with the study of the filtration media and then the tasks to complete the overall CFD model.

Experimental Team

I. Investigating the Wide Scale Impact of Integrating a *Hydro Filterra* Bioretention System within an Urban Drainage Network Using Computational Models

Outline

The network which incorporates the bioretention unit in the case study will be modelled using Storm Water Management Model 5 (SWMM5) which is a software based rainfall-runoff simulation. Analysing the model under a variety of rainfall conditions relevant to its geographical location shall enable the performance of the system to be compared with traditional systems. Assessment of water quality and network capacity will be used to measure the potential of the unit within the network as a sustainable solution to modern day water treatment problems.

Objectives

1. Model the *Hydro Filterra* system within the case study drainage network, calibrating the model using both the experimental and then the CFD results
2. Run these models under a range of conditions to comment on the differences between each method on a macro scale
3. Determine the feasibility of using bioretention systems on a large scale as a sustainable solution to modern day drainage and water treatment problems

Deliverables

1. Two calibrated models of the urban drainage system case study, incorporating the bioretention unit
2. The model of the network with standard inlets as opposed to bioretention units
3. Comparison and analysis of both models with regards to overall performance as an urban drainage system with specific regard to water quality and system capacity

II. Macro Scale Experimental Investigation to Determine the Hydraulic Properties of the *Hydro Filterra* Bioretention System with Comparison to the Hydraulic Performance of the Case Study

Outline

An experimental model of the *Hydro Filterra* bioretention system will be constructed, to enable parameter testing. The media will be analysed using both single and compound samples. This should allow for accurate calculation of the hydraulic properties. Constant head apparatus will be used and pressure gauges will be placed along the length of each sample. The test will output values for permeability, porosity, hydraulic conductivity, pressure drop across the media and flow rate through the media.

Objectives

1. Design a permeameter test rig for the *Hydro Filterra* media for laboratory testing
2. Using both single media samples and a compound sample, perform parameter tests including unsaturated trials to simulate flash floods and test with a constant head on saturated media to simulate typical rainfall events
3. Use Darcy's Law and The Kozeny-Carmen equation to verify values for hydraulic conductivity

Deliverables

1. A permeameter rig which simulates the Hydro Filterra bioretention system that can be tested for different parameters
2. Flow parameters including hydraulic conductivity for each media, including sample with a root system
3. A report on how the parameters found change under different rainfall events
4. A comparison between hydraulic performance within a lab situation and data from the case study

III. Micro Scale Experimental Investigation to Determine the Hydraulic Properties of the *Hydro Filterra* Bioretention System with Comparison to tests on a Rapid-Prototype Sample and Computer Model Based on the Micro-CT Scans

Outline

Using micro-CT scans of soil samples from the experiments detailed above, a scaled up model of the soil will be rapid prototyped for comparative fluid flow experiments. Additionally pore space geometries and micro structure of the filter media will be obtained through the scans for use in the CFD models.

Objectives

1. Support the design of the test rig mentioned above
2. Obtain core samples of the media from the test rig and complete all the micro-CT scans
3. Using scanned results construct a rapid prototyped model and complete flow tests
4. Characterise flow using Navier Stokes equations for comparison

Deliverables

1. Micro-CT scan data of all samples (both filter media and compound model) for delivery to CFD team
2. Rapid prototyped model from the scans for use in lab tests
3. Empirical data for both flow through filter media and rapid prototype model of filter media verified by mathematical models

IV. Finite Element Analysis and Optimisation Investigation into the Chamber and Protective Grate used as part of the Bioretention System

Outline

Finite Element Analysis (FEA) will be used to investigate the current design of the *Hydro Filterra* casing and protective grate. This investigation will be extended by studying alternative materials and structures to optimise the construction.

Objectives

1. Identify required mechanical performance including high pressure regions from the CFD
2. Use tensile testing to identify current material properties and use to build the FEA model
3. Determine the optimum materials for the chamber and grating under the current design
4. Optimise the shape and dimensions for the chamber and grating using iterative FEA
5. Possible extension: Investigate ways of controlling the root growth

Deliverables

1. Optimised casing and grating designs
2. Justification of the new design taking into account cost, sustainability, practicality, durability and material availability

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CFD Team

V. Three Dimensional Image Based Meshing and Computational Analysis of Fluid Flow in Various Porous Media

Outline

The flow of fluid through porous media at a micro scale is considered by analysing the flow through a small region of each porous media. Various samples will be micro-CT scanned to create 3D models which will be converted into a mesh for CFD using Image Based Meshing. The CFD will be run to determine the characteristics which define the porous media, such as the coefficients of porosity and permeability for both the *Hydro Filterra* and *Up-Flo* devices. Various flow conditions will be investigated with different levels of rainfall and transient effects.

Objectives

1. Create meshes for each media from the mico-CT data provided by the experimental team
2. Run CFD analysis on each mesh to identify the relevant flow parameters under a range of flow conditions

Deliverables

1. A comprehensive set of flow properties for each material to be provided for all macro analysis and comparison to the experimental work
2. Establish the method for creating models of this nature to provide expertise for the root system analysis

VI. Computational Modelling Of Plant Root Architecture and Fluid Absorption through Filtration Media Populated By Root Structures

Outline

The *Hydro Filterra* bioretention system utilises a plant to aid the removal of stormwater contaminants such as Phosphorus and Nitrogen. This section examines the level of fluid absorption by the root structure through the formulation of a three dimensional computational model. Specifically, the computational simulation should accurately model the hydraulic conductivity of the soil in the region and the extent of fluid absorption in the roots. This is to be completed with varying levels of soil saturation. In addition, the model should aim to represent any heterogeneity of fluid uptake across the soil region.

Objectives

1. Develop a stable and accurate, three dimensional computational model for the flow around the plant root architecture in a porous region built using values from the micro soil analysis
2. Obtain empirical values for the fluid uptake into the plant
3. Computationally determine the flow characteristics through the region containing root structures

Deliverables

1. The CFD mesh using image based meshing from micro-CT data of root scans completed by the experimental team
2. The fluid absorption rate of a root system of comparable length and density to that modelled
3. Flow parameters of a porous region including root structures to be used for macro CFD by others

VII. Macro Scale Computational Analysis Including Porous Media and Free Surface Interaction

Outline

A CFD model of the *Hydro Filterra* system is to be built on a macro scale. The system to be solved will comprise of at least three sections of porous material. Each of these domains will allow the fluid to filter through as determined by both the micro sections of the CFD analysis, to be completed by others. The modelled fluid should include a multiphase interaction of air and water with appropriate boundary conditions. The turbulence of the flow is to be modelled along with a gravity fed surge condition.

Objectives

1. Create a CFD model between its inlets and outlets with at least three media regions
2. Run the model with different initial conditions including varying saturation levels
3. Compile these macro models with the macro analysis of the interfaces from the following section into a final working CFD model of the entire system

Deliverables

1. A working model of a single media using simple inlet / outlet boundary conditions
2. A working model of a single porous media as above with multiphase flow
3. A working CFD model of multi-media multi-phase flow
4. A full macro model of the entire system, featuring a number of different flow conditions

VIII. Macro Scale Computational Analysis of the *Hydro Filterra* Storm Water Drainage System in an Industrial Urban Environment

Outline

The fluid flow that interfaces with the *Hydro Filterra* system is to be comprehensively modelled and analysed at the macro level. Different flow conditions shall be taken into account and analysis will also include transient effects and time-dependent flow behaviours. The models should represent accurately the case study example in terms of geometry, model inputs and other physical constraints. This will ensure that any computational analysis can be verified against the available empirical data.

Objectives

1. Successfully model the macro elements of the *Hydro Filterra* unit including the surface run-off adjacent to the system and inlet flow, considering optimising the installation.
2. Model the flow behaviour through the outlet of the unit in a similar fashion
3. Compile these macro models with the macro analysis of the internal media
4. Areas of further study may include multi-phase flow for contaminants such as diesel.

Deliverables

1. OpenFOAM model of surface run-off into the units from the case study featuring a number of different flow conditions, rainfall rates, transient flow conditions and free surface effects
2. A similar model of outlet flow
3. A full macro model of the entire system, featuring a number of different flow conditions

Gantt Chart

The project Gantt chart is included on the following page. Each individual section is outlined with respect to project deadlines while allowing for the flow of information between individuals. Tasks which are universal across the whole group are also highlighted along with the times the workshop is available as ascertained in discussion with the Lab Technicians.

ID	Task Name
1	LW - Define Project, Background Reading
2	LW - Research and define macro-experimental methods
3	LW - Permeameter Test Rig Design Phase
4	LW - Construction and Assembly of Test Rig
5	LW - Initial Lab Experimentation
6	LW - Experimentation on compound systems
7	LW - Analysis of MacroScale Test and Permeameter Results
8	LW - Retesting
9	JP - Define Project, Background Reading
10	JP - Research and define micro-experimental methods
11	JP -Micro CT Core sample extractor and testing case design
12	JP - Micro CT Testing on control sample
13	JP - Lab Experimentation and MicroCT of single samples
14	JP - Rapid Prototyping and testing
15	JP - MicroCT of compound samples and Lab experimentation
16	JP - Analysis of Rapid Prototype results vs Permeameter and CFD
17	JP - Retesting
18	SR - Define Project, Background Reading
19	SR - Research mechanical performance parameters
20	SR - Obtain samples of current materials and modify for testing
21	SR - Tensile Testing and Compression testing on design materials
22	SR - Construction of FEA Model
23	SR - Determination of Optimum materials
24	SR - Iterative FEA testing of different dimension designs
25	SR - Determination of Optimum Dimensions
26	SWG - Define Project, Background Reading
27	SWG - Research Case-Study (dimensions and parameters)
28	SWG - Construct Model of Case-Study using SWMM5
29	SWG - Calibrate model using CFD and Experimental Results
30	SWG - Run models under a range of conditions
31	SWG - Investigate macro scale variances between different flow conditions
32	SWG - Re-calibrate models based on modified CFD results
33	SWG - Conduct feasibility studies
34	SP - Define Project; Background Reading
35	SP - Build Single Media CFD Example
36	SP - Build Multi-media CFD Case
37	SP - Specify Exact Parameters Based on Model Study
38	SP - Run CFD Model
39	SP - Run CFD of optimised design
40	AB - Learn Basics of OpenFOAM
41	AB - Generate model of flow through single media
42	AB - Build 3D Models based on MicroCT data
43	AB - Run CFD Models
44	AB - Build and Run CFD model of 'Up-Flo'
45	JT - Background Reading; Learn OpenFOAM
46	JT - Preliminary Free Surface Flow Runs; Surface run off simulations
47	JT - Create 1st Generation Macro Model of Surface Drainage
48	JT - Outlet Pipe Analysis - Max flow rates
49	JT - Liase w/SP and run full Macro Optimised System
50	JR - Learn OpenFOAM; Preliminary Research (Root Architecture)
51	JR - Define Working Mathematical Notation
52	JR - Construct Computational Simulation of Plant Root Architecture from MicroCT scan(s)
53	JR - Research Nutrient Absorption Rates; Determine Root Structure Porosity
54	JR - Apply Empirical Data to Computational Simulations
55	JR - Ensure compliance with soil filtration data
56	
57	Group Report 1 Deadline (ALL)
58	Individual Report 1 Deadline (ALL)
59	Group Report 2 Deadline (ALL)
60	Individual Report 2 Deadline (ALL)
61	Group Presentation Deadline (ALL)
62	Preparation and compiling of Individual and group reports (ALL)
63	Preparation and compiling of Group Presentation (ALL)
64	Laboratory Availability