FINAL REPORT

DEVELOPMENT and PERFORMANCE
of a
PEAT-BASED BIOFILTER
for
RECYCLING NURSERY RUNOFF
and
IMPROVING NURSERY WATER SUPPLIES

Report of the outcomes of a Research and Development project
supported by BioFlo (formerly Bio-Remediation) Pty Ltd and The Smart Water Fund

Smart Water Fund

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EXECUTIVE SUMMARY

For the last four years, BioFlo Pty Ltd (formerly Bio-Remediation Pty Ltd) has been developing a peat-based biofilter technology for treating various forms of wastewater. Prior to this project, BioFlo had developed the technology to the commercialisation stage for the treatment of septic tank effluent, but nothing was known of how the technology might be adapted for other wastewater streams.

Since a major part of the customer base of Biogreen (BioFlo's parent company) was in retail and commercial horticulture, application of the technology for nursery runoff appeared to be a logical extension. Certainly, regulators and the nursery industry were becoming increasingly concerned at the environmental impacts of nursery runoff, and the cost of water was itself becoming a serious issue.

The overall aim of this Project was to find the optimum peat-based biofilter design to allow run-off from nurseries to be collected and re-used without causing problems with either disease or nutrient overload.

The Project began in August 2003, and has:

- Established a demonstration system. A full-scale test and demonstration biofilter has been installed and trialled at the Olinda Nurseries site at 160 Falls Road, Olinda.

  This unit has already been demonstrated to key members of the nursery industry and to potential "promoters" of the technology, including Department of Primary Industry Development Officers, key field officers of Parks Victoria and rural distribution representatives of Wesfarmers and IAMS.
- Demonstrated the effectiveness of the system, particularly for attributes of the biofilter matrix that were not previously known. Of particular value has been the project's ability to demonstrate that very high flows can be achieved through these biofilters, using a proprietary blend of Biogreen™ peats as the biofilter matrix. Much has also been learned about how to operate and manage these biofilters, both in general and in the specific context of reclaiming nursery run-off.

  The chemical and biological effectiveness of these biofilters, already indicated by results from an established system in Swan Marsh, has essentially been confirmed. In particular, the biofilter matrix has been confirmed to remove key plant pathogens, particularly the major plant pathogenic fungus of concern to Victorian nurseries, *Phytophthora cinnamomi*.
- Generated design data, which indicate that the system as built at Olinda can handle in excess of 250,000 L of run-off per day on a continuous basis. Given that this system has a physical footprint of less than 50 square metres, this in turn indicates that the biofilter technology should be applicable to essentially any nursery in Victoria. Specifically, the data allow us to provide a detailed and specific system plan and specification to any nursery that should enquire, and have allowed us to develop a simple check-list for scoping and pricing proposed systems.

Based on an expected typical installed cost of $26,500 for a "basic" unit able to process 100,000 L per day, an annual throughput of 30 megalitres and a fifteen-year service life, **the cost per megalitre of reclaimed water is less than $60**.

PROJECT AIMS

The overall aim of this Project was to find the optimum peat-based biofilter design to allow run-off from nurseries to be collected and re-used without causing problems with either disease or nutrient overload. The collected run-off is by no means a clean resource for re-use, because it contains various substances that could damage a nursery's plants. These substances include:

- excess nutrients
- suspended solids and organic matter
- salts
- insecticide and herbicide residues and
- micro-organisms, including plant-pathogenic bacteria, fungi and nematodes.

The specific objectives of the Project were to:

- establish a demonstration system on a medium / large scale commercial nursery at Olinda Wholesale Nursery, 160 Falls Road, Olinda, 3788;
- demonstrate the effectiveness of peat-based biofilters for enabling nurseries to recycle all their water (Effectiveness at cleaning run-off water in this context has been assessed by independent laboratory analysis, ability to meet flow demands, and costs per litre of water cleaned), and
- generate design data to allow the size and filter matrix of the biofilter to be predicted accurately for any nursery, based on the expected run-off chemistry and utilisation flow rates.

The principal focus was on establishing and then characterising the ideal blend of ***Biogreen***™ humic and/or fibrous peat with other ingredients to form the biofilter matrix. The ultimate ambition of this Project was to produce and validate a system that would enable commercial and retail nurseries to recycle and reuse their water economically. This has the potential to save over 1000 ML / year of water per annum in Melbourne alone.

Construction

Within the overall aims of the project, it was considered important to gain experience with the construction of these biofilter units, particularly with respect to the practicability of the construction instructions in the original conceptual designs. Subsequent trials and experiments with the biofilters were also conducted with the on-going evaluation of the construction and form of the units constantly in mind.

Once the final design for a typical installation was agreed, the costs of the construction phase were reviewed with a view to arriving at a typical cost for an installed unit – an essential piece of information for promoting these biofilters to the industry and beyond.

Flow Studies

With passive biofilters such as these, particularly where the biofilter matrix is made up of materials that are poorly permeable in their native state, flow rate is a critical issue, dictating in turn the overall area and therefore cost of the biofilter bed.

Accordingly, considerable effort was expended to determine both overall flow rates and the characteristics of flow-rate change as the filter units became established. Establishing overall flow rates would provide design data that would allow the size of a biofilter for a typical nursery application to be determined accurately.

Chemical and Biological Performance

Siting the biofilter on a large commercial nursery was undertaken on the assumption that the filter would be used to treat "real" nursery run-off at full, in-the-field scale rather than laboratory scale. The aim of this aspect of the project was to determine the purification / removal efficiency by processing large quantities of water.

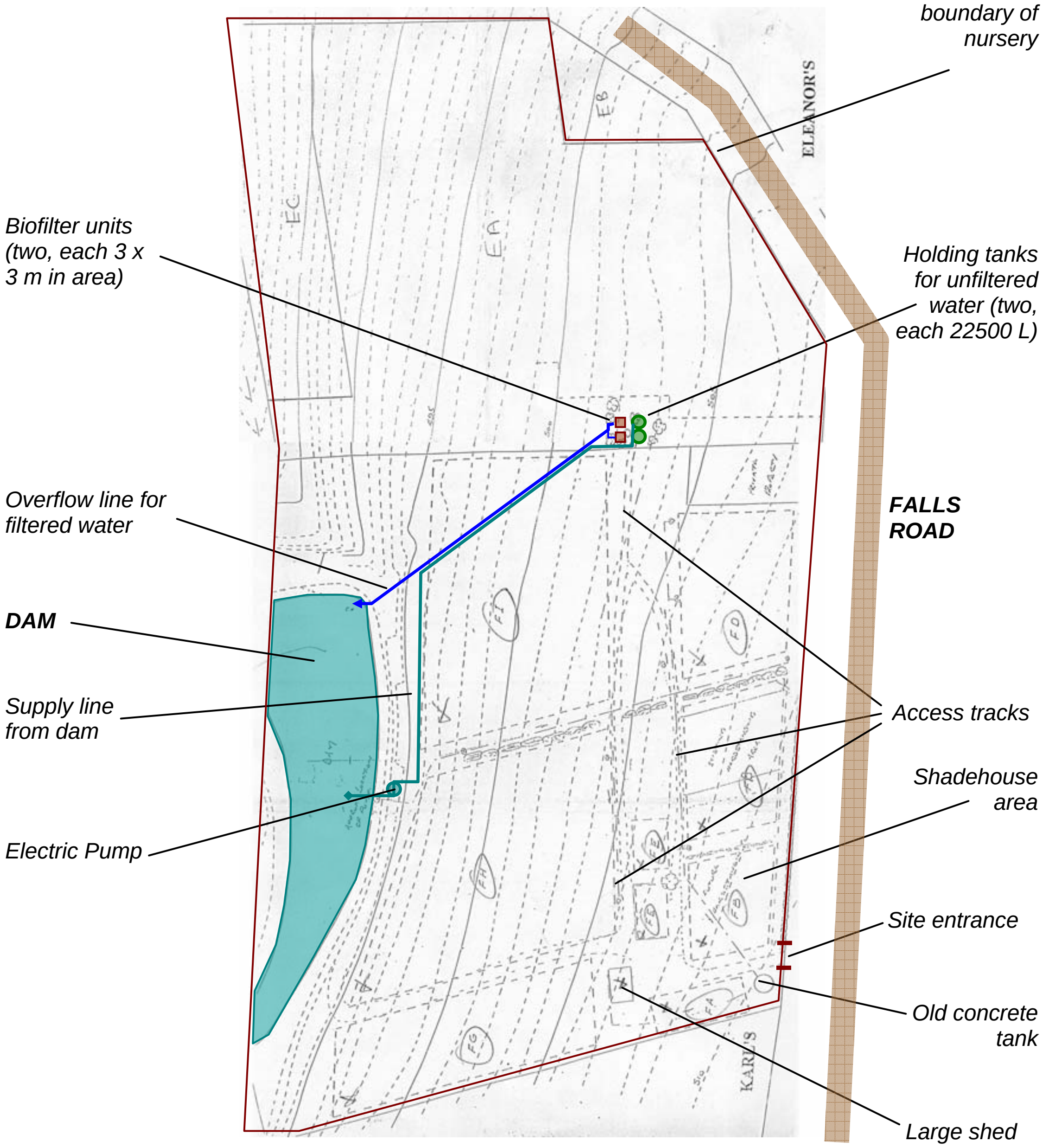
The principal concerns expressed by nurseries contemplating reclaiming / recycling their run-off include whether or not the reclaimed water will be sufficiently clean for nursery use from a chemical point of view, whether or not the recycling process will remove plant and other pathogens, and whether or not the process can prevent problems from nutrients running off site (see also Table 7, page 17). Each of these concerns was addressed in this project.

SITE LOCATION

The test and demonstration biofilter has been installed at Olinda Nurseries' site at 160 Falls Road, Olinda, Victoria, 3788, about 1 km to the south of Olinda Nurseries' main wholesale site at 110 Falls Road, Mt Dandenong, 3767.

Within the Falls Rd site, the biofilter is located as shown in Figure 2:

Figure 2 – Site Plan



The biofilter test and demonstration system is located approximately 100 m to the north of the site entrance, and is accessed from either of the vehicle tracks leading from the works area on the site's southern boundary.

As can be seen from the site photographs in subsequent sections, the system comprises pairs of identical 22500 L tanks and 3 x 3 m biofilter modules constructed under a group of large, mature eucalypt trees, and is not immediately evident from Falls Road.

The biofilter system is located at an elevation of approximately 13 metres above the surface of the dam on the western boundary, and approximately 6 metres below the level of Falls Road to the east.

Most of the growing of established and advanced trees and shrubs at the site occurs in the southern half, and run-off from this part of the site drains naturally to the dam. Water from the dam is pumped up to the biofilter's twin holding tanks, and then, after passing through the filter, is returned back to the dam. On completion of this project, the filtered water will be diverted to a storage tank that will be connected to the nursery's reticulated watering system.

CONSTRUCTION of the BIOFILTER

The construction of the test and demonstration biofilter at Olinda is summarised in Figures 3 - 6. Photographs of the system are collected in Appendix I.

Figure 3 – Schematic Overview (plan view)

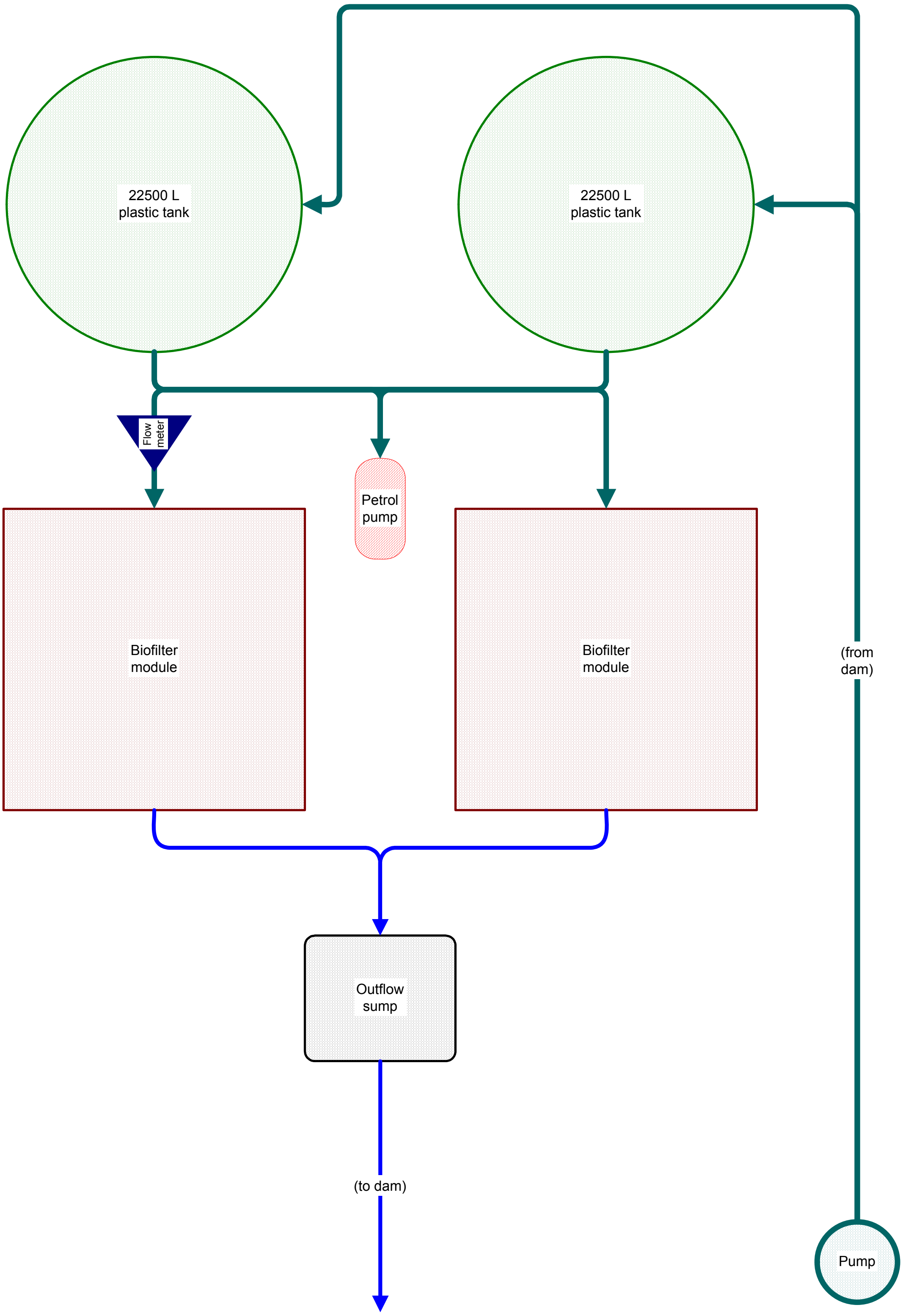
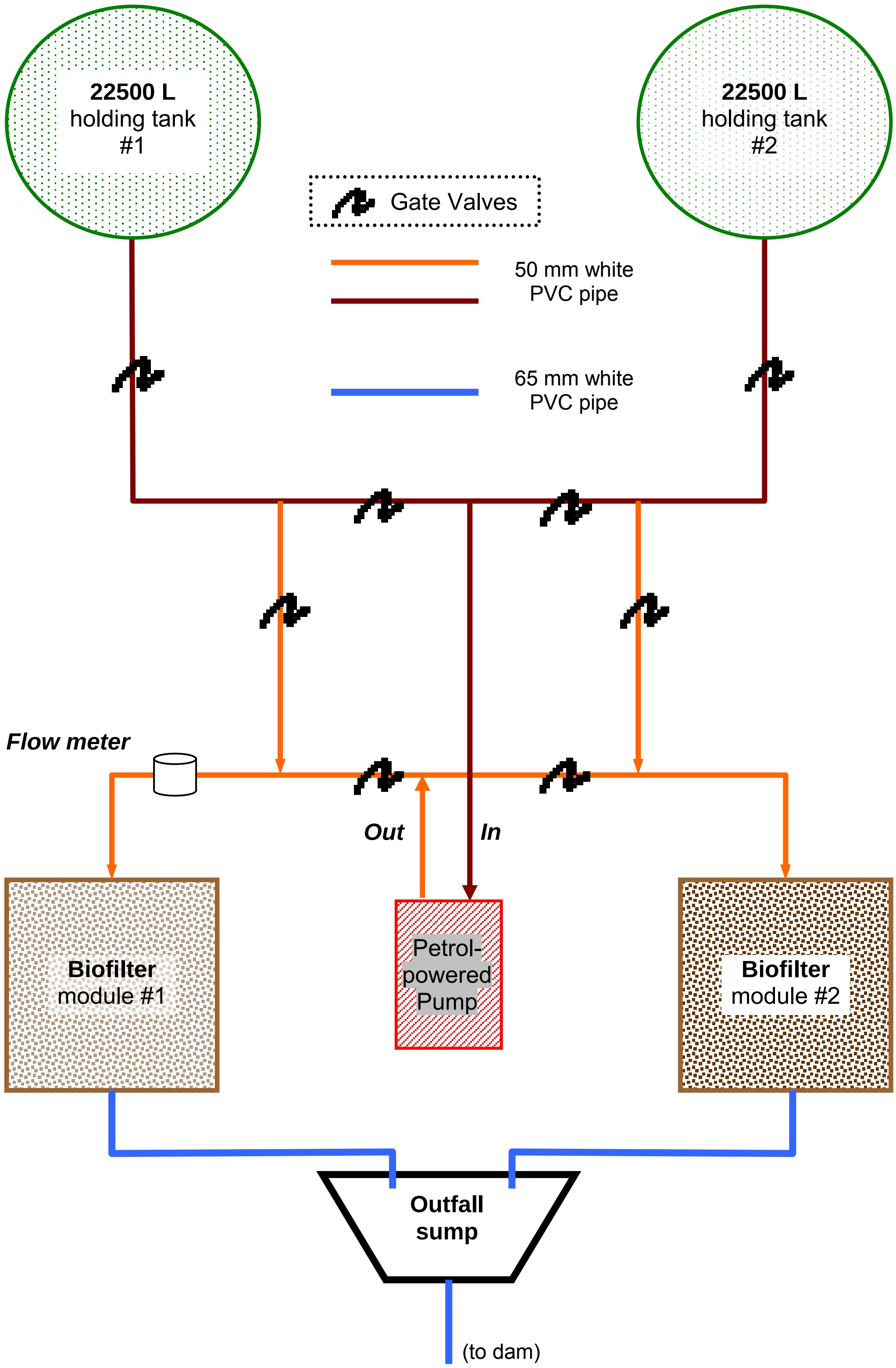
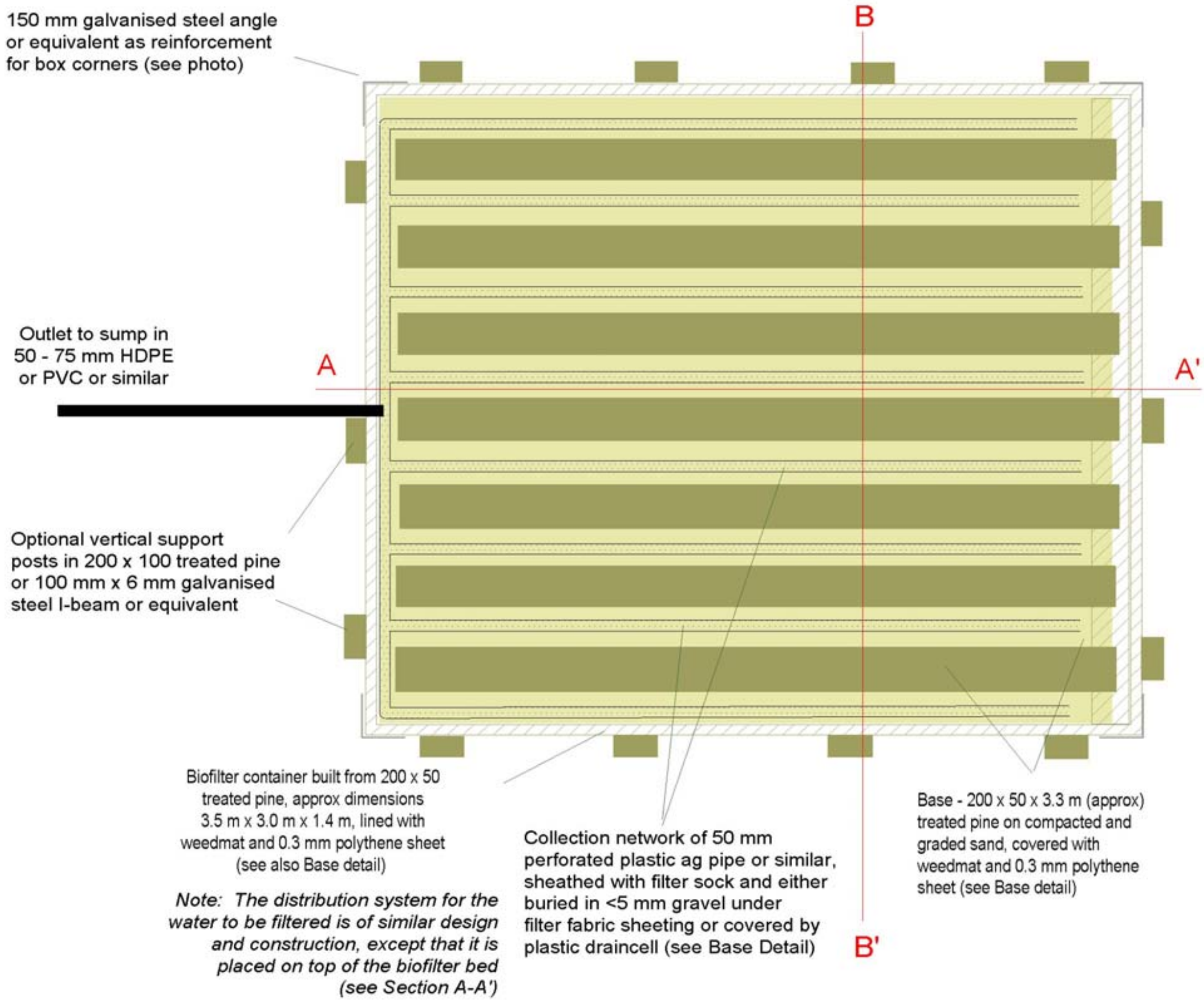


Figure 5 – Schematic Overview (Valving and pump system as installed)



With this arrangement it is possible to transfer water to and from each tank, and to feed either biofilter module with water from either or both tanks. Water can be supplied to the biofilters either under gravity or under pressure via the petrol-powered pump. Water drains to and from the outfall sump under gravity flow only. All taps are simple manual 90 degree gate valves. Detailed specifications of all parts are provided in **Table 1**.

Figure 6a – Biofilter Module Construction Plan – Plan View



Overview of System Design and Function:

1. Water is pumped from the dam by a high-output electric pump to either (or both) of the header tanks. In normal operation, the pump is activated by a pressure-differential switch set to supply power to the pump whenever the water in the tanks falls below a pre-determined level. (However, for many of the experiments conducted here, the pump was activated manually with the tanks at less than full capacity.) The tanks are also fitted with an overflow line that connects to the outfall drain from the outfall sump.
2. The collected dam water is drained or pumped from either (or both) of the header tanks into either or both of the biofilter modules. The distribution pipework at the top of each module spreads the water evenly over the surface of the biofilter matrix, through which the water percolates under gravity. Drainage from the tanks delivers water to the biofilters at up to 95 litres per minute, while pumping increases the delivery rate to nearly 180 L per minute.
3. Filtered water is then collected by the lower distribution pipework, from which it drains to the outfall sump. In the test and demonstration unit, the filtered water is returned to the dam, but in a typical installation the water would be drained or pumped to a storage tank, and then re-used in the nursery.

Table 1

Installed Components of the Biofilter System

Item	Number / Quantity	Details
High output pump at dam	1	Onga 415 V centrifugal pump model OJ 800, fitted with a pressure switch and 50 mm outlet.
Water storage tanks (header tanks)	2	Tankmasta Series TA 1407 22730 L (Serial numbers 7464 & 7473)
Storage tank float valve	2	On inlet lines from dam pump.
Gate Valves	8	Standard 50 mm 90 degree PVC
Transfer pump	1	Onga Model 350 pump powered by a Honda GX 160 petrol motor (5.5 hp)
Flow meter	1	ManuFlo model MEHR40 flow meter plus ManuFlo model FRT303 flow logger
Biofilter modules	2	As per Figures 3 – 6, each comprising:
Steel supports	8	U-beam 35mm x 55mm internal, x 2.0 m
Steel supports	4	H-beam 70mm x 55mm internal, x 2.0 m
		(set 600 mm deep in concrete)
Sleepers for walls	48	50 mm x 200 mm x 1.5 m H4 treated pine
Sleepers for base	15	50 mm x 200 mm x 3.0 m H4 treated pine
Black HDPE liner	~ 25 m^2	200 micron
Geotextile	2 x ~ 9 m^2	Grade A34 *Bidim*® from Geofabrics Australasia Pty Ltd (manufacturer), or similar. *Note*: for many applications, 70% shadecloth can be used
Pea gravel	~ 0.4 m^2	<5 mm bluestone screenings
Distribution manifold spreader bars	2 sets	8 x 2 m x 50mm PVC pipes, drilled with 3.0 mm holes at 50 mm centres, with end caps and T pieces to suit (see Figures 3 – 6 and Appendix 1).
Outfall sump	1	Standard 450 x 450 x 450 mm fibreglass-reinforced 4-inlet sump, with grate.
Pipework	(as required)	To header tanks: 65 mm PVC to AS To / in biofilter: 50 mm PVC to AS From biofilter to sump: 75 mm PVC From sump: 100 mm PVC

FLOW STUDIES

Residence Time

Overview

One of the key parameters for any biofilter is the time during which the liquid being filtered remains in contact with the biofilter matrix. In an open-draining saturated biofilter (ie, a filter in which the matrix is completely wetted / hydrated, in which the filtrate drains through the matrix under gravity, and in which there is no restriction to the outflow) this can be measured as the time it takes for a given charge of liquid to appear at the outlet.

Initial Experiments

To begin the flow rate experiments, the filter was saturated by loading the matrix with approximately two bed volumes (20,000 L) of dam water from the storage tanks. The filtrate, enriched in fines from the new peat matrix, was allowed to drain back to the dam overnight. Next day, the biofilter matrix was assumed to be saturated, but “dry” with respect to free-draining water, since there was no flow at the outlet.

A measured volume of water (806 L) was run onto the filter surface as rapidly as gravity feed from the tanks would allow (92 L / min), and allowed to flow through the filter under gravity. The time for the first trickle to appear at the outlet, for the top surface of the biofilter to appear entirely “dry” (ie without pooled water on the surface) and the time until the filter stopped running, were recorded for three successive runs on the one day.

Table 2 – Initial Loading Experiments

Run Number:	1	2	3
First flow at outlet (min):	10.5	11.0	10.5
Dry draining time (min):	11.5	12.0	12.0
Last flow (min):	122	121	121

This data suggests that the minimum residence time was approximately ten minutes, based on the time from “dry” to first flow following loading with sufficient water to fully flood the upper surface. This parameter appears to depend directly on the bed depth. The time to penetrate the surface, and the total free draining time, are both measures of the overall porosity of the matrix, and are dependent on the volume of the biofilter bed. The free draining time provides a measure of the completeness or otherwise of the saturation of the matrix, and, for any given loading of water, reaches a plateau value if / when saturation occurs.

Residence Time Validation Experiments

Contact time flow experiments were repeated numerous times throughout the course of this project. The following is a typical sample of the results:

Table 3 – Residence Time

Run Number:	12	20	32
First flow at outlet (min):	11.5	11.0	10.5
Dry draining time (min):	12.5	12.0	11.5
Last flow (min):	132	124	127

This indicates that the operational residence time of the biofilter is approximately 10 – 12 minutes. Continued operation of the Olinda system has confirmed this figure for both biofilter modules.

Maximum Flow Rate Studies

Initial Experiments

Initially, because the saturation state of the biofilter matrix was uncertain, and because we wished to avoid channelling caused by too rapid flows, it was not possible to determine flow rate by adjusting the input flow to reach equilibrium conditions, ie where the level of free water in the biofilter above the reticulation pipework stayed at a fixed level while the filter flowed. Rather, the filters were loaded with a single charge of water to the practical capacity of the freeboard above the reticulation pipework, ie 806 L, and the various flow times determined thereafter, as indicated above.

A residence time of approximately 10 minutes suggests that each biofilter module could process approximately 6 x 806 L loads (ie 4836 litres) per hour. This is equivalent to 116,064 L per day, or to a **maximum** processing capacity of just under 13,000 L per square metre per day.

Since there are very few nurseries with run-off flows much in excess of 120,000 L per day, this suggests that the biofilter construction and biofilter matrix used in this project is nearly adequate for most nursery run-off applications, provided this figure is correct.

Alternatively, based on the time it takes to pass 806 L completely through the biofilter (ie dry to dry), it can be argued that the **minimum** treatment capacity is approximately 12 x 806 L per day, or 9,672 L, or approximately 1,075 litres per square metre per day.

To provide a measure of corroboration of the flow rates calculated from residence time, a charge of approximately 380 L was loaded onto the surface of a pre-saturated filter every ten minutes for four hours. The time taken for the surface to "dry" (ie to the point where there was no ponded water) was measured, with a view to determining whether there was any increase in dry draining time. A sample of recordings is presented here:

Table 4 – Cycle time experiments

Iteration # & time (min):	2 (13:06)	8 (14:06)	18 (15:46)	25 (16:56)
Dry draining time (min):	4:45	4:30	4:40	4:30

After four hours of loading with 24 x 380 litre charges, there was no apparent increase in the dry draining time, suggesting that the biofilter matrix was draining sufficiently fast not to back up with water at this loading rate. During the four hours of this test, the biofilter processed 9,120 litres, implying a daily rate of 54,720 L, or a processing capacity of 6,080 L per square metre per day. Given that the filter surface was dry for approximately half of each ten-minute period, and assuming that accordingly the loading rate could be approximately doubled, this value corresponds very closely to the maximum processing capacity inferred from the residence time.

Flow Rate as a Function of Filter "Age", and Flow Rate Validation Experiments

In our initial trials, the filtrate collected from the filters looked like dilute coffee, with a cloudy, deep golden brown appearance. Based on the colour and suspended solids in the filtrate, it appeared that the flow rate of the biofilter becomes faster, at least up to a point, as the peat fines are washed out of the matrix (see Table on the following page).

Given that each of the biofilter modules at Olinda contains approximately 72,000 L of peat matrix, it appeared that, at maximum flow rate, it would take at least 6 - 8 bed volumes of filtrate (ie at least 432,000 L) at full flow to wash a new filter clean.

Using water from the dam at Olinda Nursery's Falls Road site, ***consistent*** flow rates of the order of at least 14,500 L / m^2 / day have been proven. This flow rate was the maximum that could be achieved by gravity feed with the current configuration at Olinda, but is considered to be substantially higher than will be required by the great majority of nurseries.

Table 5 – Flow Rate Development

Run #	Volume filtered*	Cumulative volume	Flow rate (L / m^2 / day)	Turbidity score*
6	3120	15,050	11,220	5
8	2400	20,000	12,850	5
10	2400	26,000	13,110	4
11	6200	33,170	13,980	2
12	7705	42,650	14,550	1
15	3150	52,500	14,500	<1
20	2325	63,190	15,500	3
32	6645	71,320	14,775	2
36	7215	84,240[†]	14,800	1

*: at maximum gravity flow rate from supply tank (92 L/min), except Run 20 (110 L/min)

**: against a Barium Sulphate opacity scale (1 unit = ~10 NTU).

[†]: estimated value – cumulative flow meter malfunctioned and was replaced

Run 20 was particularly interesting because there was a significant return to the turbidity and colour of earlier runs. This may have been because the filter had been inactive for about two weeks prior to this run, and had dried out somewhat. Further, the two storage tanks had been refilled to maximum capacity, meaning that the loading rate under gravity was approximately 15% higher (110 L/min *cf* 92 L/min). Subsequent runs, at flow rates of about 100 L/min, show a progressive reduction in colour and turbidity.

Summary Of Flow Rate Determinations

Table 6 – Summary of Flow Rate Data

Parameter*	Value	Units
Residence time	10 - 11	mins
Dry draining time	10 - 11	mins
Processing capacity – upper limit	15,506	L / m^2/ day
Processing capacity – lower limit	1,075	L / m^2/ day
Daily flow capacity – maximum measured	155,062	L / day
Daily flow capacity – minimum measured	9,672	L / day
Probable typical capacity	14,400	L / m^2/ day
	~10	L / m^2/ min

* Using ***Biogreen*** Certified Biofilter Blend Type NF1, batch 03002 as filter medium.

Factors Affecting Flow Rate and Performance:

Biofiltration Matrix Composition

In its native state, Biogreen black peat is highly impermeable and, indeed, conventional European wisdom had it that black sedge peats could not perform nearly as well as the European sphagnum peats in biofiltration applications. Experiments conducted before the commencement of this project nevertheless demonstrated that blends of Biogreen peats could be made to produce media with a wide range of porosities (see Appendix 2).

Moreover, Biogreen peats have been shown by Dr R. Patterson of LanFax Laboratories (and others) to bind more nutrients and pollutants per unit weight than sphagnum, and, indeed, Biogreen peats are the only natural matrix to bind phosphorus to a significant extent (see below and Appendix 3). Accordingly, this Project was undertaken in the belief that effective biofilter blends for nursery water purification applications could be formulated from Biogreen peats.

The initial choice of biofilter blend used in this Project was based on data for the fastest – flowing blends in SRS study (see Appendix 2). The blend was also modified in the light of improvements to the processes used for "manufacturing" the different peats at Biogreen's Swan Marsh facility, to produce peats that were both more porous and more hydrophilic than those available at the time of the SRS study. Further, based on chemical studies by Dr Patterson, it appeared that the absorption capacity for various nutrients and pollutants – particularly phosphorus - depended on the amount of humic matter and the amount of clay in the peat.

Loading the Biofilter Cell, and Precautions for Optimum Performance

The certified biofilter blend is supplied in either bulk bags or 25 kg pillow packs. It should be tipped loosely from these directly into the biofilter box, and the accumulated material raked level, but not compacted, regularly as more material is added. Once the appropriate amount of matrix has been added to the box, the top surface should be raked lightly but carefully to dead level and covered with geotextile or shadecloth to prevent disturbance by moving water. (The Olinda units both had exposed distribution manifolds, and there was some erosion of the matrix directly beneath the pipes.)

In order to maximise flow and efficiency, it is clearly important to prevent compaction of the biofilter matrix. Therefore we use draincell or scoria rather than bluemetal as the porous medium to surround the upper distribution manifold, to minimise the weight pressing down on the filter. Similarly, it is obviously important that the surface of the filter is not trafficked - if pedestrians or vehicles must cross the filter, it is essential to cover the filter with a material that is sufficiently strong to support the weight clear of the filter surface. The strength of the biofilter container may also need to be modified to carry the added weight. (Conventional wooden decking and treated pine sleepers have both been used successfully in domestic biofilters where pedestrian or vehicle access is required.)

The biofilter matrix should ***not*** be disturbed once in place. In particular, the matrix must not be stirred or manipulated while flooded and under slow flow conditions. It appears that this stirring causes fine particles of peat to suspend in the water, only to settle as a heavy layer on the surface, blocking all the spaces within the upper layer of the matrix. For similar reasons, the untreated water should be applied to the biofilter matrix in as dispersed a fashion as possible – in particular, streams and trickles should be broken and spread through gravel, draincell and/or shadecloth so as to minimise disruption of the biofilter matrix surface.

CHEMICAL AND BIOLOGICAL PERFORMANCE

Standards

Guidance on what constitutes acceptable quality in recycled nursery water has been drawn from the Victorian EPA's Publication 464.2 – *Guidelines for Environmental Management: Use of Reclaimed Water* (June 2003), from *Water quality and nursery crop nutrition* (The NGIA Nursery Papers, issue 2002/11, pages 1 – 2, published by the Nursery and Garden Industry of Australia), and from *The Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC / ARMCANZ, October 2000). These publications provide acceptance criteria for various chemical, physical and microbiological parameters in nursery water to be applied to plants.

In arriving at a set of acceptance standards for this project, it was also decided to include a limit for the water-borne root pathogen *Phytophthora cinnamomi*, which can be a cause of significant crop losses in the Melbourne area. Further, recognising that there may be some circumstances in the nursery industry where it is not possible to re-use the run-off water processed by the biofilter, it was also important to consider standards for water to be discharged to the environment. Phosphorus, in particular, was included because it is widely used in nurseries, it is retained poorly by many potting media, and is acknowledged as a major cause of algal blooms and eutrophication in natural waterways that receive run-off water.

The acceptance criteria adopted for this project are shown in Table 7 below.

Analytical Suite

The analytical suite selected for the project was chosen to reflect the species of concern to both environmental regulators and nursery operators, while at the same time providing information that was useful in the development and fine-tuning of the biofilters. Accordingly, several parameters, including *Phytophthora*, total and bacteriocinogenic *Pseudomonas* species, various nitrogen species, and total phosphorus, were included. Further, emphasis was placed on those species that were likely to be a problem in run-off (as distinct from the water supply itself), because they would originate from the potting media, fertilisers and surfaces of the typical nursery.

Table 7 – Analytical Suite

Parameter*	Units, etc	Limit	Parameter*	Units, etc	Limit
BOD_5	mg/L	10	***Cadmium [Cd]***	mg/L	0.05
TSS	mg/L	5	***Chromium [Cr]***	mg/L	1.0
Total N	mg/L	125	***Copper [Cu]***	mg/L	5.0
NH_4 – N	mg/L	10	***Lead [Pb]***	mg/L	5.0
Nitrate N	mg/L	ns	***Zinc [Zn]***	mg/L	0.2
Nitrite N	mg/L	ns	***Presumptive coliforms***	cfu/100 mL	10
Total P	mg/L	1.00	***Pseudomonas***	cfu/100 mL	ns
Conductivity	µS/cm	950	***Bacteriocinogenic pseudomonads***	cfu/100 mL	ns
pH	(units)	5.5 – 7.0	***Phytophthora cinnamomi***	zoospores/L	*<10* *****

ns: No standard relevant to nursery use is available in Australia.

*: Adopted as a preliminary guideline

Analytical Results

Water samples were collected after various of the flow rate runs at the Olinda site, and sent to an independent analytical laboratory to be analysed for key wastewater / irrigation water parameters, as shown in the table below. The performance of the biofilter blend used at Olinda was also evaluated against water from a polluted nursery dam near Monbulk. For comparison, the Table also includes data from a septic tank effluent biofilter installed at our Swan Marsh facility. (This biofilter uses the same biofilter matrix blend as the Olinda nursery unit, but has been in operation, processing STE, for over three years, and therefore represents an established system.)

As indicated above, emphasis was placed on those species that were likely to be a problem in run-off (as distinct from the water supply itself), because they would originate from the potting media, fertilisers and surfaces of the typical nursery. Data presented in this Table are ***median*** values, based on analysis of individual water samples.

Table 8 – Summary of Laboratory Analytical Data [#]

Parameter	Units	Acceptable limit^	Olinda Dam		Monbulk Dam		Swan Marsh STE	
			In	Out	In	Out	In	Out
No. samples	n		4	5	1	1	27	27
BOD_5	mg/L	*10*	<5	<5	-	-	78	7
TSS	mg/L	*5*	8	20	-	-	59	6
TKN	mg/L	*125*	1.4	6.2	6.3	5.9	58	3.6
NH_4 – N	mg/L	*10*	-	-	<0.3	0.4	67	5.9
Nitrate N	mg/L	*ns*	0.4	0.5	16	13	<0.2	61
Nitrite N	mg/L	*ns*	<0.05	<0.05	0.56	0.18	0.007	0.03
Total P	mg/L	*1.00*	0.036	0.18	4.2	0.52	7.8	1.6
Conductivity	µS/cm	*950*	79.5	160	540	410	790	820
pH	(units)	*5.5 – 7.0*	6.8	6.4	6.9	6.4	7.3	5.0
Cadmium [Cd]	mg/L	*0.05*	<0.005	<0.005	-	-	0.01	<0.005
Chromium [Cr]	mg/L	*1.0*	<0.03	<0.03	-	-	0.9	<0.03
Copper [Cu]	mg/L	*5.0*	<0.01	0.04	-	-	0.8	0.05
Lead [Pb]	mg/L	*5.0*	<0.06	0.07	-	-	12.5	0.10
Zinc [Zn]	mg/L	*0.2*	0.04	0.04	-	-	23	0.03
Presumptive coliforms	cfu/100 mL	*10*	70	80	-	-	1.6×10^6	8.6×10^4
Pseudomonas	cfu/100 mL	*ns*	>2000	>3300	-	-	-	-

-: Not tested
[#]: Medians. Copies of the original analytical certificates can be found in Appendix 4
ns: No limit specified
^: The highest concentration considered to be acceptable for nursery watering use (see p17)

COMMENTS and OBSERVATIONS on THESE RESULTS:

The water from the supply / run-off dam at Olinda has been very clean, as can be seen from the median figures in Table 8 above. Given that the biofilter began with new matrix material, which is known to contain dust and fines, it was unlikely in hindsight that meaningful absorption data could be obtained by using this water alone as input. Indeed, on the early figures, the biofilter reduces the water quality, rather than improves it!

However, this by no means invalidates the project or the results. The flow data itself indicates that filters of this size will take some time, and considerable flow through, before they will run clear (which data from all our other biofilters, including recent data from the minesite filter, indicate does happen), and the trends are in the right direction.

In particular, a "purging" experiment, in which biofiltrate samples were collected shortly after the commencement of a flow rate study, and then after some 5,000 L had been through the matrix (see Samples 1107 & 1108 in the Report of 12 February, 2004, in Appendix 2 A), critical analytes such as TKN, TOC, total Phosphate and conductivity all dropped significantly. Interestingly, TSS including the presumptive pseudomonads remained constant or increased slightly, suggesting a progressive elution or displacement of particulate matter and microbes from the matrix.

(The high result for pseudomonads was unexpected, suggesting that further differentiation into potentially plant pathogenic species and others will be required – a dedicated project at Monash University to address this is proposed for later in 2004. It is likely that many of the organisms appearing in the laboratory test as "Pseudomonas" will actually prove on further investigation to belong to other species.)

The Monbulk "Gerbera" Dam

The results for phosphate and heavy metals (Cd, Cr, Cu, Pb and Zn) further confirm that the Olinda dam water is very clean. One of the ambitions of this Project was to demonstrate the efficiency of peat biofilters at absorbing phosphate and heavy metals, which the Olinda system is too clean to do. It has proved frustratingly difficult to locate water samples that are sufficiently contaminated to be useful, particularly where issues of access and confidentiality became involved.

Nevertheless, one source on public land was located near Monbulk. A sample from this dam, which was moderately infested with various algae, and down slope from a paddock of rotting plant stems and a gerbera growing greenhouse, was collected. Three litres of the sample were processed by shaking gently with six litres of the same batch of biofilter matrix material as was used in the Olinda system. After fifteen minutes, the suspension was filtered rapidly through an analytical filter, and the sample submitted for analysis.

Table 9 –Laboratory Analytical Data from the Gerbera Dam Samples

Analyte	No contact	15' contact	Analyte	No contact	15' contact
pH	6.9	6.4	Ca	44	26
EC	540	410	Mg	11	14
TKN	6.3	5.9	Na	17	36
Nitrate	16	13	K	46	2.7
Nitrite	0.56	0.18	Total Fe	0.92	1.0
Total P	4.2	0.52	Total B	0.13	0.11

Phosphorus and potassium were notably reduced from the exceptionally high levels in the dam, as was calcium, while sodium increased. This may well have been because of displacement of sodium by calcium and potassium ions binding to the peat matrix. These results indicate the speed with which phosphate removal can occur in these matrices (see also "Establishment", below).

Removal of Plant Pathogens and other micro-organisms

It is important to note that the Olinda Nurseries site was ***disease-free*** during the entire Project, and that, accordingly, it was not possible to determine the action of the biofilters against existing plant disease organisms in the field. Correspondingly, it would have been inappropriate and irresponsible to introduce samples known to be infected with specific disease organisms to Olinda. Accordingly, the following studies were conducted under controlled and contained conditions (and strict quarantine, in some cases) in laboratories, using small columns of the same biofilter material as used at Olinda.

Phytophthora cinnamomi

Phytophthora cinnamomi is a soil-borne, root-pathogenic fungus that spreads as motile zoospores through water. This fungus is one of the major threats to Australian native plants and many introduced plant species. The aim of this part of the project was to determine whether Biogreen peat biofilter blend removes *Phytophthora cinnamomi* zoospores from water. Initial experiments at Melbourne University, using a pathogenic strain of *Phythophora*, indicated that this was the case, and are to be completed and fully documented later in 2004. The preliminary experiment reported below, carried out at Monash University, appears to confirm the likely performance of the filter matrix.

Materials and Methods

Columns containing 40 mL of biofilter blend (10 replicates) or washed river sand (10 replicates) were set up in 60 mL syringes and equilibrated with sterile distilled water for 4 hours and then allowed to drain dry.

40 mL of a suspension of *P. cinnamomi* zoospores (10^4 per mL of a non-pathogenic isolate of strain ATCC 11928) was applied to each column and allowed to drain through. Six hours later, the columns were flushed with a further 40 mL of sterile distilled water. Both filtrates were checked microscopically for the presence of motile zoospores immediately the filtrates were collected. The microscopic examination involved five 2 µL aliquots taken from the filtrate collected from each separate syringe.

Results

Mean and standard deviation counts for the microscopic screening are shown in the following table:

Table 10 – Recovery of P. cinnamomi

	***P. cinnamomi* zoospores per 2 µL aliquot (mean ± SD)**	
	Peat biofilter blend	Washed river sand
Initial suspension	18 ± 3	18 ± 3
Initial filtrate	<1	9 ± 4
Flush filtrate	<1	6 ± 2

Results are significantly different at $p < 0.05$.

Discussion

Given that a very heavy inoculum of *P. cinnamomi* zoospores was used, these results indicate that the peat biofilter blend appears to arrest and retain zoospores of this species very effectively, to the point that they are not able to be recovered from the filter matrix. While sand also removes some of the zoospores, they can be eluted subsequently. This suggests that the peat is either converting the spores into a non-motile stage or is actively killing them. Which of these possibilities is actually the case will need to be resolved by cultural or other methods, but it appears likely that the peat biofilter material will actively remove *P. cinnamomi* zoospores from nursery run-off water. In this context, it is worth noting that the level of zoospores expected in a nursery situation, even where disease is rampant, is likely to be less than 10^2 zoospores / mL.

Plant-pathogenic pseudomonads

Various species of the genus *Pseudomonas* cause a range of diseases in plants, while other members of the genus are antagonistic to these pathogens. Since pseudomonads are a major component of the microbial flora of Biogreen peats, it was of interest to investigate the effect a peat-based biofilter might have on plant-pathogenic species of Pseudomonas. However, experiments similar to those performed with *P. cinnamomi* (see above) are difficult to interpret because there is a large number of pseudomonads in the normal filtrate from the peat matrix.

The basis of the antagonism between various pseudomonads is frequently due to the production of *Pseudomonas*-specific bacteriocins, which are low molecular weight extracellular toxins. One approach to investigating the likelihood that the biofilter matrix would be antagonistic to plant pathogenic pseudomonads would be to determine whether any of the resident pseudomonads produce extracellular toxins active against a plant pathogenic species such as *Pseudomonas syringae*.

Materials and Methods

Typical filtrate from fresh biofilter matrix contains between 30 and 90 cfu / mL of pseudomonads. Fresh aliquots of Olinda dam water and the subsequent biofiltrate were centrifuged and the pellet resuspended in $1/10^{th}$ the original volume of isotonic saline. This suspension was diluted a further 1:5, and 100 μL aliquots of both dilutions were spread over pseudomonas-selective nutrient agar (Oxoid *Pseudomonas* CFC Agar) and incubated at 28 °C for 24 hours. The plates, which bore between 10 and 300 discrete colonies on their surface, were then exposed to chloroform vapour (which kills the vegetative bacteria but not the anti-pseudomonal activity) for five minutes. A 5 mL agar overlay seeded with *Ps. syringae* (FDA strain PCI 841 [X205]) was applied to each plate, which was then incubated for a further 18 hours at 28 °C. The proportion of colonies showing a “halo” or clearing zone around the colony in the *Ps. syringae* layer was then determined.

Results

In separate determinations, 15, 24 and 31 percent of pseudomonads present in three separate filtrate samples from the Olinda biofilter showed antagonistic activity against the plant pathogenic *Ps syringae* indicator.

Discussion

A significant proportion of the pseudomonads resident in the biofilter matrix expressed inhibitory activity towards the plant pathogenic species *Ps. syringae.* While it has not been possible to prove that the peat biofilter matrix will actually remove all plant pathogenic pseudomonads from nursery water, this result suggests that some form of removal and inhibition is likely. This conclusion is supported by the reported absence of pseudomonas infections in potting mixes formulated with Biogreen peats.

(Human) Microbial Pathogens

Although we do not have specific data, it is possible that nursery run-off could contain microbial species that are pathogenic to humans. This would particularly be the case where animal or poultry manures were used as fertilisers. However, detection of the potential pathogens that could be encountered, such as *Bacillus* and *Clostridium* species, the enteric pathogens such as *Salmonella* and *Shigella*, and *Legionella pneumophila*, can be an uncertain and expensive exercise unless specific species are suspected. Accordingly, it is accepted practice to investigate indicators of faecal contamination, such as thermo-tolerant coliforms. Although the levels of thermo-tolerant coliforms in the Olinda dam water were very low, and too low to indicate the effect of passage through the biofilter matrix, data from Swan Marsh consistently indicate that the biofilter matrix used at Olinda causes a dramatic reduction in the numbers of these indicator species in the filtrate. From this it is inferred that the Olinda biofilters should certainly remove enteric pathogens from run-off to acceptable levels.

Samples of the biofilter matrix material were examined for the presence of *Salmonella* and *Legionella* species in the laboratory. Neither was found in two separate samples, from two different production runs.

Establishment

One of the fundamental attributes of our biofilter matrices that we did not understand at the outset of this project was the rate at which the filters can develop their various biofiltration capabilities. Determining the establishment rate for these activities is only possible with samples that contain appreciable amounts of the analytes in question (and the Olinda dam water collected in the biofilter header tanks did not, over a period of six months). Accordingly, additional, more polluted run-off samples were sourced from dams in nearby Monbulk, and run through the matrix to determine the rate at which removal activity appeared.

Total Suspended Solids and Conductivity

It was originally anticipated that Total Suspended Solids (TSS) would be a useful indicator of establishment of the biofilter matrix. After approximately four months of ***intermittent*** operation, the Olinda biofilters were still showing appreciable levels of TSS in the filtrate (see Table 8 on page 18). By contrast, the Swan Marsh biofilter, which has been in operation for approximately four years, is consistently delivering filtrate with TSS <10. From first principles, it can be argued that if the TSS in the filtrate is indeed peat fines and tannins, the TSS value will eventually stabilise at a low value, probably as a function of both the total volume of water that has passed through the matrix, and the flow rate of that water. Certainly, samples taken early and late during substantial flow rate experiments, where >5000 L were passed through the matrix at a flow rate of approximately 10 L / sq. m / minute, showed a significant reduction in turbidity and TSS (see Table 5 on page 15 and the "Purge" samples in Appendix 2A), although it also appeared that there was a greater level of fines in the filtrate after the filter had sat idle (but saturated) for some time. This is likely to be due to the slow dissolution of humates and tannins from the matrix – a process that would both decline with use and be minimised with constant flow. Preliminary reports (still being confirmed as this Report was prepared) from the Green Chemistry Centre at Monash indicate that, as expected, the bulk of the TSS in recent filtrate samples is humates and related humic substances. This material should actually be beneficial to plants.

The current matrix at Olinda is still shedding both the "fines" that come with the Biogreen reed sedge peat component, and some soluble matter (contributing to the slight increases in Conductivity seen in Table 8). As indicated by the results from the older Swan Marsh biofilter, the Olinda biofilter should be able to achieve TSS < 10 once established. As indicated above, it appeared that, at maximum flow rate, it could take at least 6 - 8 bed volumes of filtrate (ie > 432,000 L) at full flow to wash a new filter clean.

Conductivity is not reduced by passage through the biofilter. Indeed, in most cases there has been a slight increase in Conductivity (see also Table 8). However, it appears that much of the increase is due to replacement of sodium and other monovalent cations in the input water with calcium and/or magnesium in the filtrate, resulting in a reduction in the Sodium Absorption Ratio (SAR) (*Dr Bob Patterson, personal communication*). This suggests that while these biofilters can not remove sodium, they may nevertheless help plants combat salinity by contributing divalent cations.

Nitrate and Phosphate

Data from the Olinda system and several of our other biofilters indicates that nitrate is unique amongst the chemical species in runoff and other inputs in that it actually ***increases*** consistently in the filtrate wherever there are significant levels of HN_3 and/or TKN in the input water. (It should be noted here that there is nevertheless a ***total reduction*** in all nitrogen species of 40% or more.) Nitrate is generated by processes requiring both oxygen and carbon dioxide by consortia of microbes including *Nitrosomonas* and *Nitrobacter* species. It would appear that these nitrogen-metabolising microflora become established in the biofilter as its ability to remove nutrients and organic pollutants develops. Therefore, because of the ease with which nitrate can be measured with a reasonable degree of accuracy even in dirty matrices, this analyte was tested as a possible indicator of the establishment process.

At the same time, removal of phosphorus – which is assumed to rely largely on physicochemical rather than biochemical removal processes – was also monitored.

The data summarised in the table below are the average results from two different run-off samples, where sub-samples of the same batch of run-off were run through the matrix at the times indicated, and the filter allowed to sit undisturbed between runs:

Table 11 – Rate of action

Hours after first contact	**Concentration of analyte in filtrate***		
	[NH_3] (ppm)	**[NO_3]** (ppm)	**[PO_4]** (ppm)
0 (no contact)	15	15	55
0.1	15	15	20
4	15	15	5
9	10	20	<1
20	3	25	<1
48	<0.25	30	<1
72	<0.25	50	<1
170	<0.25	50	<1

*: determined using both ***Merckoquant*** and ***Hach*** test strips.

This data suggests that while phosphate sorbtion develops very rapidly (and is most likely a physical absorption and therefore virtually instantaneous in an otherwise equilibrated system), the development of nitrogen-metabolising activity - specifically the ability of the matrix to convert NH_3-N to NO_3 (an activity known to be characteristic of peat biofilter matrices) – takes several days to develop. This is not surprising given that the increase in activity is likely to require growth of all the organisms in the nitrogen-metabolising consortium and then biochemical induction of the relevant enzyme systems.

These observations are in accord with both overseas and our own experience. Once this filter is converted to be a permanent part of Olinda's watering system, this issue of establishment time will be re-examined, especially since, at this site in particular, it may only be necessary to run the filter during the summer months.

Treatment Efficiency vs Flow Rate and Bed Depth

This project was not able to investigate the relationship between flow rate and treatment efficiency, or between matrix bed depth and treatment efficiency, largely because of the quality of the Olinda dam water. However, our experience with similar filters elsewhere (treating more concentrated inputs) indicates that treatment efficiency ***does*** depend on both variables. As a rule of thumb, filter **capacity** depends on **surface area**, while filter **efficiency** depends on **contact time** (which is a function of flow rate and/or bed depth).

We have confined our design data to a single bed depth at this stage, although this will be investigated later in 2004. In general, these biofilters should be operated at the lowest flow rate required to achieve the required level of treatment of the input water, but this must be balanced with the daily flow demand and the capital cost of the filter. Accordingly, the Design Ready-Reckoners in Appendix 5 express the relationships between Daily Flow Volume and Cost, and Daily Flow Volume and Filter Area, as a series of curves reflecting typical flow rates.

ACHIEVEMENT OF PROJECT GOALS

1. ***Establish a demonstration system:***

This has been achieved. A full-scale test and demonstration biofilter has been installed and trialled at the Olinda Nurseries site at 160 Falls Road, Olinda.

This unit has already been demonstrated to key members of the nursery industry and to potential "promoters" of the technology, including Department of Primary Industry Development Officers, key field officers of Parks Victoria and rural distribution representatives of Wesfarmers and IAMS. A series of Open Days for all members of the LIAV, municipal environmental health officers, representatives of the water authorities and the EPA, and other interested parties, are planned for July and August 2004. Important insights into the time (and water volume) required to bring the current biofilter matrix to equilibrium have also been gained.

2. ***Demonstrate the effectiveness of the system:***

This has been achieved, particularly for attributes of the biofilter matrix that were not previously known. Of particular value has been the project's ability to demonstrate that very high flows can be achieved through these biofilters, using a proprietary blend of Biogreen™ peats as the biofilter matrix. Much has also been learned about how to operate and manage these biofilters, both in general and in the specific context of reclaiming nursery run-off.

The chemical and biological effectiveness of these biofilters has essentially been confirmed, and accepted not only by the owners of Olinda Nurseries but also by key members of NGIV. Of particular interest to the nursery industry, the biofilter matrix removes and appears to kill key plant pathogens, particularly *Phytophthora cinnamomi,* the major plant pathogenic fungus of concern to Victorian nurseries.

The clean state of the Olinda dam was unexpected, and has somewhat limited the benefit of installing the biofilter in a "live" context. Although it was originally intended to import more contaminated water for treatment, quarantine and disinfection concerns have currently limited this approach, until issues such as the fate of pathogens and residual contaminants trapped in the biofilter matrix has been comprehensively resolved. Large scale laboratory systems (50 L – 450 L) for checking these aspects have been built, and BioFlo intends to run a continuing research program into these aspects throughout 2004.

3. ***Generate Design Data:***

This has been achieved. The data obtained indicate that the system as built at Olinda can treat up to 250,000 L of run-off per day on a continuous basis, delivering water that is suitable for most nursery uses. Given that this system has a physical footprint of less than 50 square metres, this in turn indicates that the biofilter technology should be applicable to essentially ***any*** nursery in Victoria.

Specifically, the data allow us to provide a detailed and specific system plan and specification to any nursery that should enquire, provided

- the purpose of the unit and its output (ie minimising off-site impact and/or re-use of reclaimed water, for watering and/or washing),
- site layout (including reticulation and drainage lines),
- site topography,
- typical water consumption and/or watering patterns, and
- typical run-off composition

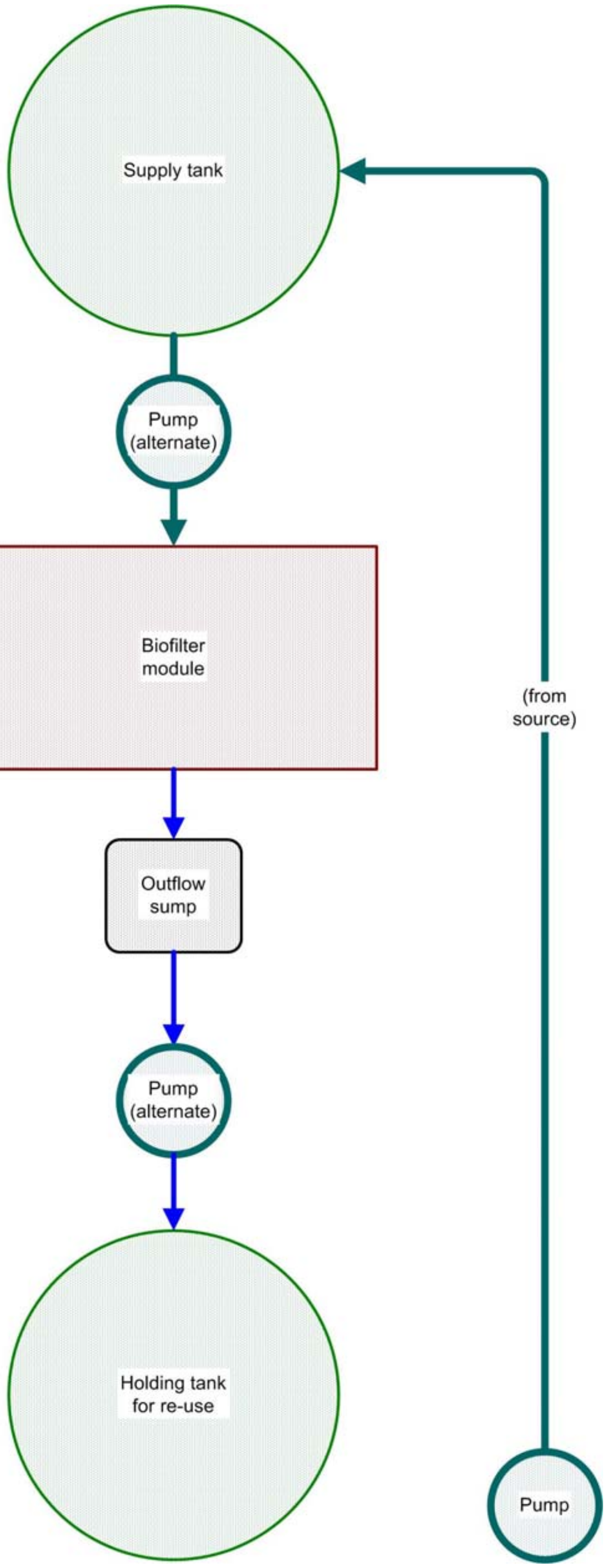
are known and/or can be determined. Graphs showing the relationship between water demand, system size and cost are presented in **Appendix 5**.

Based on an expected typical installed cost of $26,500 for a "basic" unit able to process 100,000 L per day, an annual throughput of 30 megalitres and a fifteen-year service life, the cost per megalitre of reclaimed water is less than $60 (see below).

SUMMARY of TYPICAL NURSERY BIOFILTER SYSTEM

Design and components

Figure 7
Layout and Components of a Typical Nursery Biofilter System



Expected capital costs of typical system

Table 12 – Cost Summary

Item	Number / Quantity	Cost estimate	Comment
High output pump from source	1	$ 2000 - 3000	Varies with site / size
Water storage tanks (delivered)	2 (or more)	$ 4000 - 7000	Varies with site / size. One tank serves as a holding tank for dirty water, the other for the biofiltrate
Storage tank float valves	2 per tank	$ 850	
100 mm overflow line			Varies with site / size
65 mm pump line from dam			Varies with site / size
50 mm high pressure pipe, manifolds and valves	1 set	$ 300	As per Figure 5
9 m^2 biofilter module comprising			
Custom-built housing	1	$ 4000	
Biogreen Certified Biofilter Blend	6.5 m^3	$ 2500	
Outfall sump	1	$ 715	Includes grating
Plumbing – labour, etc	48 h	$ 3000	
Documentation for installation and regulatory approval		N/C	
TOTAL COSTS		**~ 20,000**	**For complete system**

Projected operating costs – treatment cost per kilolitre

This “basic” unit would be able to process 100,000 L per day, to give an annual throughput of 30 megalitres of re-usable water.

We expect the biofilter matrix to last at least 15 years, but, as a worst case, we have assumed the matrix will need to be relaced every five years in this application. Accordingly, the total lifecycle cost can be summarised as

Capital (installed) system cost:	$20,000
Annual maintenance:	15 x $100 max
Additional Biofilter blend:	2 x $2500
TOTAL LIFECYCLE COST:	**$26,500**

Given a fifteen-year service life, the cost per megalitre of reclaimed water is less than **$60**.

APPENDICES:

1: A Photographic Summary

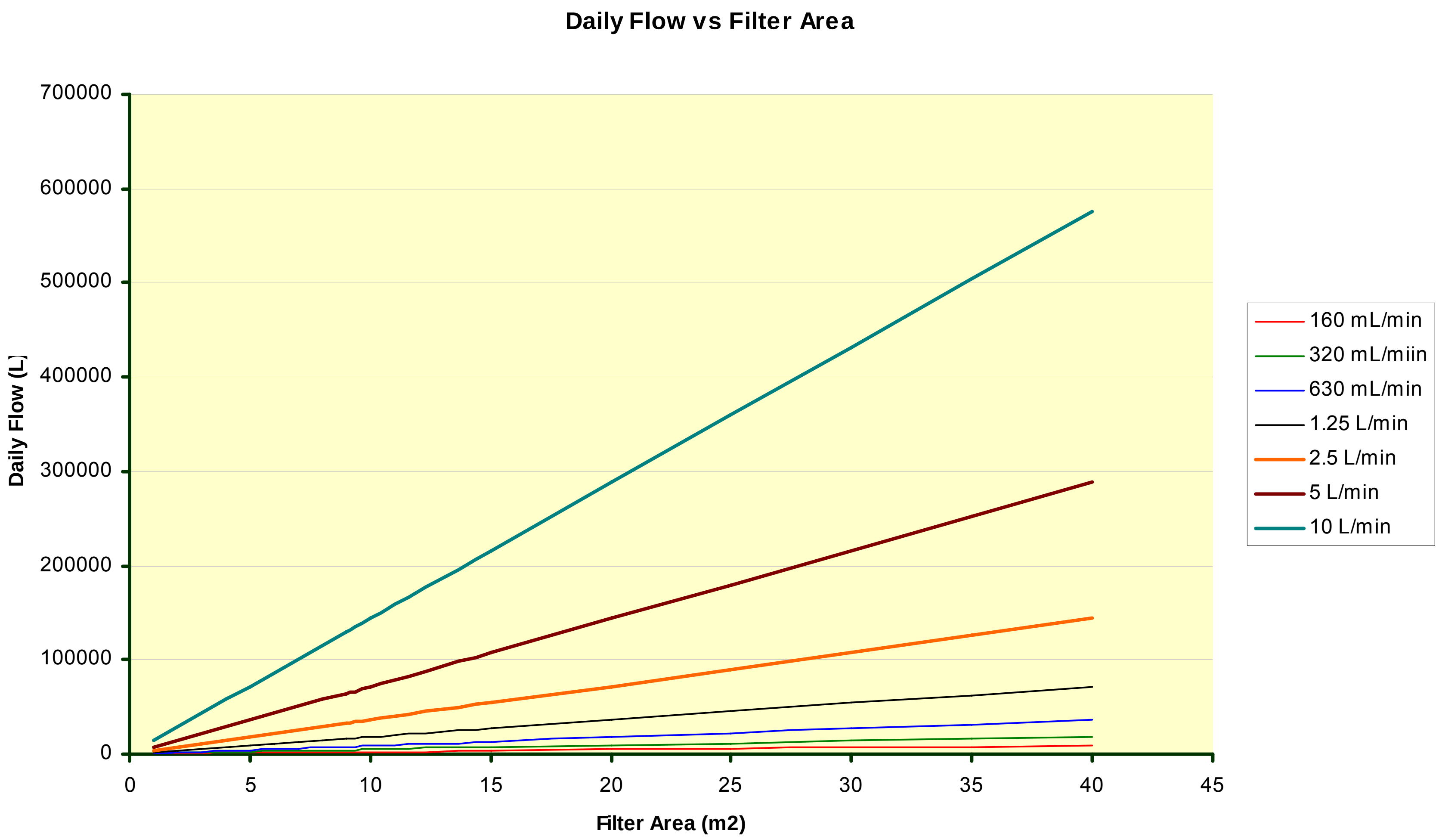
2: SRS Report

3: LanFax papers

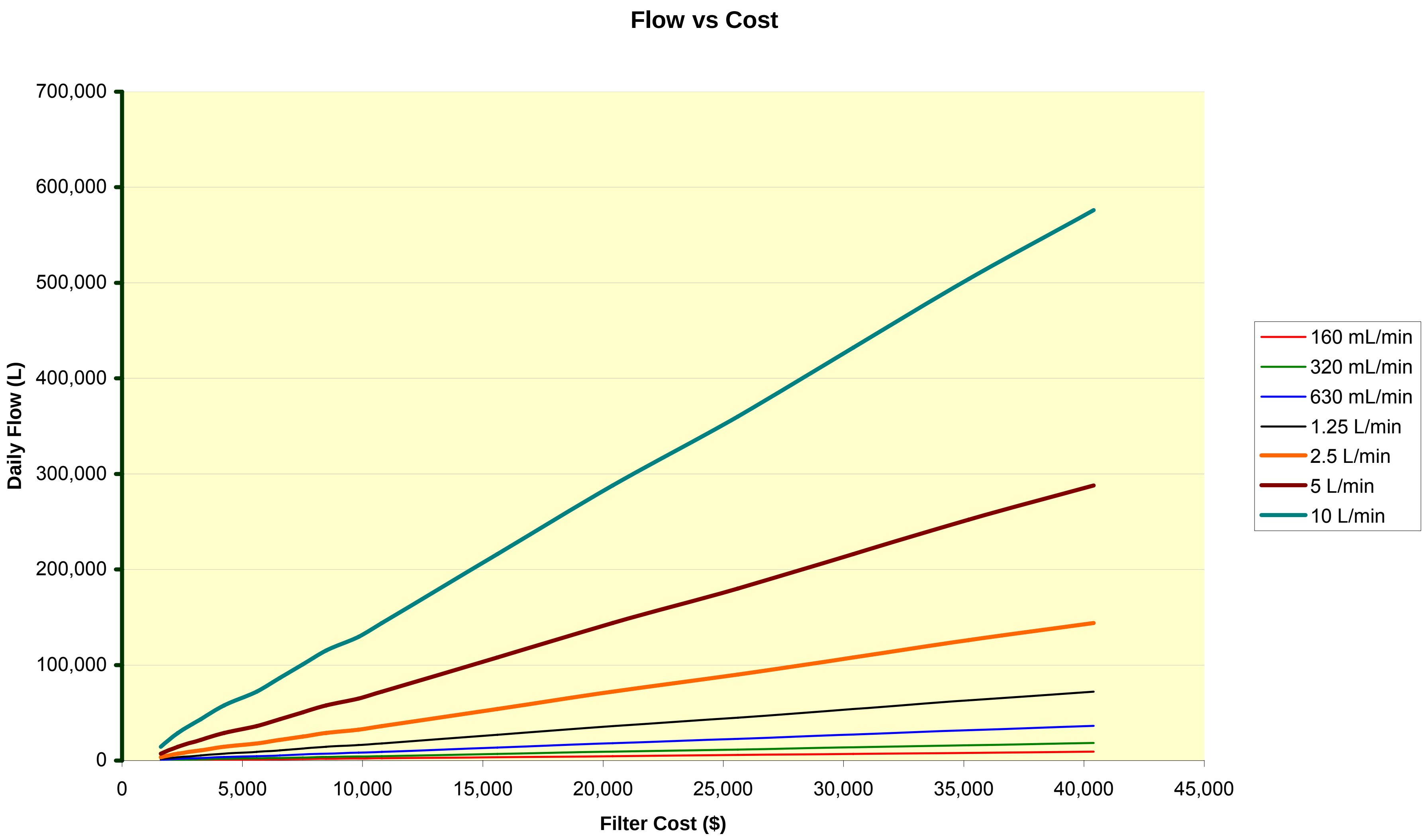
4: Certificates of Analysis and Data Summaries

5: Design Ready Reckoners

APPENDIX 5
Design Ready-Reckoners



Appendix 5 – READY RECKONERS, cont'd



Appendix 5 – READY RECKONERS, cont'd