TAMK University of Applied Sciences
Degree Programme in Environmental Engineering
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Final thesis

Planning of laboratory scale grey water recycling systems

Supervisor Senior Lecturer Eeva-Liisa Viskari
Commissioned by TAMK University of Applied Sciences
Tampere 12/2009

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December 2009
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ABSTRACT

The purpose of this thesis is to outline the particulars of constructing a laboratory scale grey water recycling system. This work is intended to be used as a guide for anyone who wishes to construct such a system. This thesis topic was suggested so that in the future someone can construct such a device for their own thesis work. It is intended that a working device be realised for use in the new greenhouse complex which is scheduled for construction in 2010 at Tampere University of Applied Sciences (TAMK).

The function of this grey water recycling system is intended to take diverted grey water from one sink in the green house and purify this grey water to the extent that it is suitable for plant hydration.

This thesis outlines each component and suggests options for differing components’ operations. There is a complete wastewater recycling system of basic configuration outlined in this thesis. It is envisioned that the creation of such a device will be successful and problem free if the recommendations presented in this thesis are adhered to.

It is indeed possible to filter and utilise recycled grey water which is suitable for plant hydration with quite simple purification devices. The main challenge for designing such a system is deciding on the intended capabilities of the system in terms of capacity, level of purity of recycled grey water and the possible expansion of the system.

Keywords waste water recycling, grey water, water filtration

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Planning of laboratory scale grey water recycling systems
31 sivua
Lokakuu 2009
Ohjaaja: Lehtori Eeva-Liisa Viskari
Toimeksiantaja: TAMK Tampereen ammattikorkeakoulu

TIIVISTELMÄ

Tämän tutkimuksen tarkoituksena on määritellä laboratorioskaalassa rakennetun harmaan veden kierrätysjärjestelmän yksityiskohdat. Työn on tarkoitus toimia oppaana harmaan veden kierrätysjärjestelmän rakennusprosessissa, sekä pohjana mahdolliselle järjestelmän rakentamiselle esimerkiksi opinnäytetyönä. Harmaan veden kierrätysjärjestelmää on suunniteltu kasvihuoneeseen, joka on määrä rakentaa Tampereen ammattikorkeakouluun (TAMK) vuonna 2010.

Harmaan veden kierrätysjärjestelmän toimintaperiaatteena on ohjata kasvihuoneesta lähtevä harmaa vesi puhdistettavaksi, jotta vettä voidaan myöhemmin käyttää kasvien kasteluun.

Tämä tutkimus määrittelee järjestelmän jokaisen komponentin ja ehdottaa vaihtoehtoja eri toiminnoille. Työssä on esitelty jätevedenkierrätysjärjestelmän perusrakenne. Näkemyksenä on, että tässä esitetyn järjestelmän kokoonpano on ongelmatonta, mikäli esitettyjä suosituksia seurataan.

On todellakin mahdollista suodattaa ja käyttää kierrätettyä harmaata vettä, joka on sopivaa kasvien kasteluun yksinkertaisella puhdistusjärjestelmällä. Suurimmat haasteet tällaisen järjestelmän suunnittelulle asettavat kysymykset kapasiteetista, harmaan veden puhdistusasteesta ja järjestelmän laajennusmahdollisuuksista.

Avainsanat jäteveden kierrätys, harmaa vesi, veden suodattaminen

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1 Introduction

Waste water recycling had been going on in many water poor areas such as Australia for a long time now (Malkovic 2006). Waste water can be divided into three groups, they are: Black water, which consists of human faecal material and urine as well as anything else that might end up in the toilet. Domestic grey water, which consists of cleaning chemicals, shower water and other water, that ends up being drained from one of the house hold sinks. Industrial grey water, which generally is more hazardous than domestic grey water because it consists of materials such as waste substances from industrial processes and other high concentration chemicals which are not necessarily related to industrial processes. If the industrial grey water is of such a type that it is too difficult for wastewater treatment plants to nullify sufficiently then it is usually set aside onsite for treatment or other disposal which is pertinent to the hazardous class of waste.

This thesis topic was suggested to me by my thesis supervisor Eeva-Liisa Viskari. Tampere University of Applied Sciences (TAMK) is scheduled to undergo a remodelling of one of its blocks. A new greenhouse complex is going to be constructed there and it is the wish of some of the teaching staff that there be a grey water recycling system be operating in that greenhouse.

In this thesis I will be concentrating on reviewing different techniques for purifying light domestic grey water in laboratory scale devices. There will be no final design of any apparatus in detail because it is impossible to know what hardware is available to the builder of such a system, but only the review of possible treatment systems will be discussed and outlined.

2 Common methods for grey water purification and/or reuse

There are a great number of grey water recycling systems available which vary greatly both in complexity, performance and also cost. These systems range between simple one house systems to very advanced treatment processes for large scale reuse. (Jefferson, Laine, Parsons, Stephenson & Judd 1999, 288.) It can be generally stated that the expense of a system is related to the final quality of treated waste water. It should also be noted that different reuse applications require different water quality specifications which demand different treatments which account for the range in complexity of available systems (Fangyue, Wichmann & Otterpohl 1999, 3440). A contributing factor to the existence of this range is that there is no internationally enforceable reuse standard to control the quality of reclaimed wastewater. There is considerable variation in national waste water guidelines internationally, particularly regarding the identifiable values and the limited parameters of quality. (Fangyue *et al.*1999, 3440).There are three main methodologies for grey water treatment; they include physical treatment, chemical treatment and biological treatment. However purification procedures usually include combinations of these methods in order to produce treated grey water with the desired characteristics.

2.1 Physical treatment systems

The physical treatments include coarse sand, fine, soil and membrane filtration, followed mostly by a disinfection step. There are also radiation technologies which utilise radiation sources such as UV, ultrasound and other photonic radiation in combination with catalysts such as hydrogen peroxide and/or ozone lead to formation of hydroxide free radicals. (Gogate & Pandit.2004, 503.) Radiation of varying forms has been shown to be effective in disinfecting and degrading pollutants in waste water. These are very advanced technology and are quite out of the scope and economy of this project.

Soil filtration however cannot be regarded as a single filter only, but a combination of filtration and biodegradation. This is because it has the capacity to remove organic pollutants and phosphors partially and due to nitrification and de-nitrification reactions which occur normally in soil and therefore have the capacity to eliminate nitrogen effectively (Fangyue *et al.*1999, 3441). Basic 2 stage course filtration and disinfection systems represent the most common domestic grey water reuse technology used in the UK This process employs a short retention time so that the chemical character of the grey water remains mainly unchanged and only minimal treatment is necessary. The course filter is usually a metal strainer which catches the larger particles and disinfection is achieved through the introduction of chlorine or bromine dispensed in slow release or by dosing a liquid solution. This technology occasionally suffers a failure in the disinfection process and coliforms are not eradicated. This is because most grey water is high in organic load and therefore high in turbidity. High turbidity is a known factor in limiting the effectiveness of the disinfection process and turbidity relates to flocculent particle content. Because grey water can contain flocculent particles in excess of 40 µm in diameter the disinfectant cannot diffuse far enough into the core of the flocs to eradicate all pathogens. A lesser reason is that in grey water which contains detergents, the detergents react with the disinfectants producing species that are not as effective at killing organisms. Simple filtration systems based on fibrous cloth or depth filters do not offer an absolute barrier against suspended solids which results in coliform breakthrough and the possibility of solids' discharging whenever there is a hydraulic shock. (Jefferson *et al.*1999, 288-289.)

This problem of organic pollutant load and therefore potential coliform break through can be remedied through the use of membrane filters as they offer a permanent barrier to suspended solids greater than the size of the membrane. The membrane sizes can be as small as 5 µm for microfiltration and can even be on the molecular scale in the case of reverse osmosis. The big drawback with this membrane technology is that the energy consumption is considerable as many of the membrane systems in use require pressures up to 2.0 bar. This energy demand obviously puts this type of technology out of the range of most home systems. Also these membrane systems require pre treatment or high maintenance cleaning because the membranes are easily fouled and this fouling increases the energy demand considerably due to greater hydrostatic resistance in the membrane. (Jefferson *et al.*1999, 289.)

If the requirements of the treated grey water are only intended to irrigate households' surround vegetation then a diversion only system is sufficient as long as this waste water is never intended to come into contact with humans. Diversion only systems simply divert the household grey water through a pipe or network of pipes underground to the roots of plants and/or trees. It is important that this waste water is not used for direct irrigation as there is a potential health risk associated with this practice (Grey Water Systems Australia 2009). The main principle of this system is that the soil acts as a filter and organic content of the grey water is absorbed by micro organisms living in the soil which adds a degree of nutrition to the surrounding living system. An upgraded version of this system would be to place a strain filter on the grey water outlet to remove large particles and oils. In general this practice, especially in the case of house hold irrigation, is to lessen the likelihood of blockages in the pipes to occur; it does not imply any extra purification of the grey water. Another physical component method is fine sand and course gravel filtration who's principle of operation is to provide a physical barrier against particles greater in size than the channels of the filter/sand, there is usually a biological component to these filters as nitrification and de-nitrification bacterial colonies soon establish themselves in the absence of disinfection chemicals. These sand filters are usually arranged as a tank in which the grey water to be treated flows through but could be arranged in a multitude of forms.

2.2 Chemical treatment systems

Common disinfection chemicals such as chlorine and bromine are used rather extensively to sterilise treated grey water however this is usually preformed at the end of a more complex treatment process simply to ensure the safety of humans who come into contact with it. It is advisable to remove the majority of suspended solids before disinfection as afore mentioned, the presence of larger organic particles is directly proportional to the efficacy of the disinfection goal (Winward, Avery, Stephenson & Jefferson 2008, 490).

More environmentally friendly compounds such as essential oils (EO) have been shown to be effective in the disinfection process. The most effective EO appears to be *origanum* EO or the oil from the oregano plant (Winward *et al.* 2008, 2264). However, there are problems associated with EOs in that the effluent to be disinfected should be quite low strength in order for the dosing of EO to remain economically viable. Also the oregano plant yields a very small amount of EO per plant mass and it is estimated by Winward *et al.* (2008, 2266) that the area of cultivated land required for the growing of oregano in order to disinfect the amount of water that an average UK household uses for toilet flushing per year would be 3000m^2.

Usually after any treatment of waste water which may include grey water, if the condition of the effluent needs to be within certain levels, there is a clarification stage. Most commonly chemical flocculation and or coagulation are used to achieve further purification of wastewaters. In the case of flocculation, chemicals such as ferric sulphate or aluminium sulphate are added to treated waste water to induce the formation of flocs, which are comprised of undigested organic material and other colloids. (Wikipedia 2009e.)

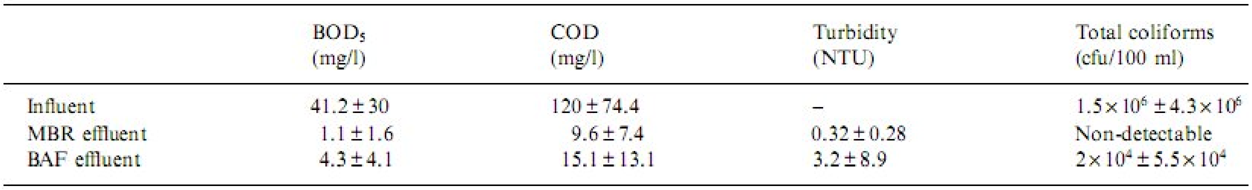
2.3 Biological treatment

The term biological wastewater treatment pertains to in its most basic meaning; biological methods of wastewater treatment is to introduce contact with bacteria (cells), which feed on the organic materials in the wastewater, thereby reducing its BOD content (Cushman-Roisin 2009). There are two main types of microbes which exist commonly on earth and they are those which require oxygen and those which do not; termed accordingly, aerobic and anaerobic bacteria. There are many ways to exploit these organisms so that they consume our unwanted organic material, and presumably the methods come under two main headings; aerobic digestion and anaerobic digestion. There are many kinds of individual biological reactors available and we will not go into that issue in detail, however the two main treatments are outlined below.

The up-flow anaerobic sludge blanket (UASB) reactor is a methanogenic digester which is commonly utilised in waste water treatment. It uses an anaerobic process and produces a blanket of granular sludge which suspends in the tank. (Wikipedia 2009d). The influent is introduced at the bottom of the tank and flows upwards through the sludge blanket where the organic material is digested by anaerobic bacteria. It is quite an effective method but requires constant monitoring in order to maintain efficacy. The methane produced in large scale operations could also be quite a resource in the sense of power generation; it could at least in theory power itself. In small house hold scale applications it is not remarkably expensive to operate.

Membrane bio reactors MBR have the ability to reduce BOD, COD, coliforms, and turbidity rather well which is shown in table X (Jefferson *et al.* 1999, 6). They are literally what they say they are a combination of aerated bio reactor and membrane filter. The membrane filtering phase eliminates the sand filtration and disinfection stage in more conventional systems.

Table 1: Performance of advanced biological systems for grey water recycling (Jefferson *et al.* 1999, 290).



	BOD_5 (mg/l)	COD (mg/l)	Turbidity (NTU)	Total coliforms (cfu/100 ml)
Influent	41.2 ± 30	120 ± 74.4	–	$1.5 \times 10^6 \pm 4.3 \times 10^6$
MBR effluent	1.1 ± 1.6	9.6 ± 7.4	0.32 ± 0.28	Non-detectable
BAF effluent	4.3 ± 4.1	15.1 ± 13.1	3.2 ± 8.9	$2 \times 10^4 \pm 5.5 \times 10^4$

Another type of general bioreactor is a range termed biological aerated filters (BAF). With this technology the waste water is pumped into the first of two tanks where it is aerated with a healthy mix of nitrifying bacteria for an extended amount of time to ensure that the bacteria have enough time to consume the organic material. The waste water then flows from the first tank into the second where it is allowed to settle and the biologically treated waste water then flows to a third tank for storage. The effluent from BAF reactors have been shown to be significantly cleaner than the influent however they are not as effective as USAB reactors in terms of purification, but they can remain effective at much higher loading rates (Jefferson *et* al 1999, 290). Most biological treatment systems require further clarification of the effluent through the chemical means of flocculation or sedimentation with the exception of the BAF, which makes it an attractive option.

3 Philosophy of laboratory scale grey water treatment system

When designing such a system there are a few main aspects to consider. What is the purpose of the device? Is it’s intention to just demonstrate the principle or principles of treatment processes’ or should it be designed to actually filter some greater quantity of water? If the scale of volume of the device is exceeded, perhaps there should be a fail safe so that the device is not over filled – after all, designers cannot rely on the competence of the operator. How elaborate should the design be in terms of components and procedures and the level of technology used? These days there are some rather expensive and effective filtering technologies which when set up and operated in the correct fashion could filter some extremely contaminated water into potable water (Water Purification: Purification Technologies 2009). However, if the water was never intended for human consumption, but just a rather effective method to reuse the water for example watering some plants which would otherwise consume water from the human supply, that level of technology and expense would be unnecessary. Another important thing to consider is the purpose of the device: is it to only filter the water and return it to the sewer where it was going anyway or shall the water be diverted to supply some activity such as watering some decorative plants or even food crops.

The outlining philosophy of constructing such a device is that it is a demonstration model and students from all over the world will see it in operation. Those students may come from water rich places where the consideration of utilising partially contaminated water is rare. Conversely this device may remind or give inspiration to those of water poor areas to become involved in this kind of recycling as the benefits would seem to be more than obvious. The device is of a limited size and therefore will have a very small impact on the actual local environment in terms of reducing pollution. However, its mere existence makes a statement that principles of sustainability need to be clearly demonstrated and will hopefully establish memes in the minds of students and staff that are able to observe its operation. It is hopeful that these memes may influence those observers to install a similar technology in their own home if or when they have the means to do so or to promote such methods in larger scale operations in their communities.

The various practicalities associated with such a device could be potentially numerous in respect to design conditions. For instance should the device be portable or stationary. Also, if the watering of plants be a function of the device should there be a design feature which allows the cleaned grey water to be directed and circulated amongst a larger than the default amount of grow area (expansion). Even a small system could potentially provide water for a whole green house if that be the wish of the designer. It is also a possibility that such a device could supply a reserve hydroponics reservoir, so that a whole system of production could be hydrated by water which was destined for the wastewater treatment plant (in countries and areas which utilise these facilities), as well as maintain its usual duties. One only needs to entertain the possibility in the design phase to provide easy implementation when the operator decides to utilise such a feature in the future.

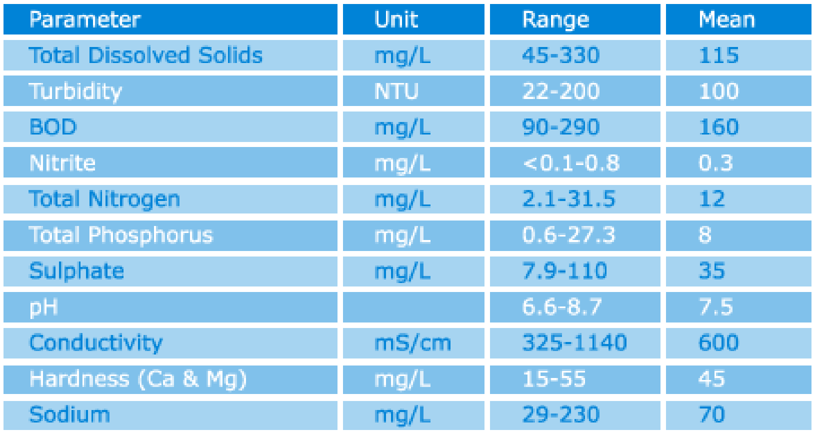
One could also potentially be overwhelmed with the range of control equipment which could be used in terms of pumps switches, level sensors, IC controllers, timers etc. It is, however, the opinion of the author that the least amount of high technology is probably best when designing such a system. Regular float switches and valves are in the opinion of the author more than satisfactory solution for controlling the devices operation. The overall design should be simple enough so that the principles of operation are clearly evident to the degree that one will be able to understand the process by observation alone. Although an electric water pump is a technological device it would indeed satisfy the simplest solution to raise water to a higher elevation and therefore be ponderous to entertain alternative methods of fluidic ascension. Especially so since the intended environment of activity is in a university of applied science's green house in an industrialised country where electric solutions underline simplicity.

The overall treatment principle is such a simple one and a high level of precision might be in a sense be unnecessary when you think of the potential hazards of a system failure. The range of failure starts from mild (the water is not purified) to medium (the plants become water logged or too dry and suffer as a result) and finally catastrophic (the system breaches and there is some amount of water on the floor which leads to other hazards related to wet surfaces and water damage to fixtures and fittings). The potential catastrophic condition of breaching would be minimised significantly if the design incorporated an overflow pipe on every high volume component of the apparatus but perhaps that amount of overflows is perhaps not a practical solution. Also the designer might like to have the device primarily gravity fed with only one main pump which elevates the water to the start condition and every subsequent component positioned directly under the component before/above it; in this configuration any leaks could drip down to the next component. This is possible by assuming the fact that most of these components are simple open vessels of varying usages and descriptions.

4 Particulars of grey water composition

The nutrient content of grey water is usually low when compared to normal mixed waste water (sewage). In some cases the level of phosphorus (P) can be high but nitrogen (N) is almost always low. In fact the P content is related to washing powder usage and could in fact be lowered to levels below that normally found in advanced treated wastewater if people were to use a P-free detergent. (EcoSanRes 2008.) Other pollutants include metals which originate from the pipe system itself, the use of shampoos and perhaps also from washing cutlery in the sink; however, it is known that these metals are low concentration contaminants in grey water. Other organic contaminants’ sources are ordinary house hold chemicals such as glues, preservatives and cleaners. People can have a major influence on these contamination levels by using environmentally friendly chemicals and by not pouring hazardous substances such as paint and solvents down the drain. (EcoSanRes 2008.) Because house hold grey water does have a factor of BOD, which is presented in table 1 along with other typical constituents, it is not advised to allow the untreated grey water to sit for any prolonged period as it quickly becomes anaerobic and foul smelling in as little as 24 hours and often contains human pathogens (Illes Hostleter 2009). Common grey water nutrient levels in Finland have be measured to be 30g/p/d of organic matter, 0.3g/p/d total phosphorus and 1.0g/p/d total nitrogen. The organic matter portion of Finnish grey water accounts for 60% of all organic matter in all types of Finnish grey water, as well as 20% of total phosphorus and 10% of total nitrogen. (Treating Domestic Wastewater in Areas Outside Sewer Networks (542/2003), article 2, table 1.) Treating and reusing grey water does hold obvious benefits to the environment in terms of nutrient removal.

Table 2: Typical values for household grey water composition (SunSureWater Ltd. 2009).



Parameter	Unit	Range	Mean
Total Dissolved Solids	mg/L	45-330	115
Turbidity	NTU	22-200	100
BOD	mg/L	90-290	160
Nitrite	mg/L	<0.1-0.8	0.3
Total Nitrogen	mg/L	2.1-31.5	12
Total Phosphorus	mg/L	0.6-27.3	8
Sulphate	mg/L	7.9-110	35
pH		6.6-8.7	7.5
Conductivity	mS/cm	325-1140	600
Hardness (Ca & Mg)	mg/L	15-55	45
Sodium	mg/L	29-230	70

5 Scale

Being the purpose of this document is to outline planning the of a laboratory grey water recycling system, scale is a very important parameter to consider. Capacity of said device does not need to be excessively large so that it becomes difficult to move that one would require major planning in order to do so. Conversely it should not be so small that the capacity of the system be unable to treat a nominal volume of grey water that the output of one sink would exceed many times over. Another consideration is the volume of treated water which is required in order to achieve functionality. If this device is used to treat all the grey water produced in a green house lab then of course the capacity of the device need be rather large, a guess would be in excess of 1000L. If the device need only treat enough water to provide moisture to some of the plants in the green house lab or all of them (which is pertinent to this case), perhaps just 100 or so litres would be more than sufficient.

The physical footprint of the unit is also important. If the finished unit is of such a size and shape that it is awkward in the space provided for it then it might become a nuisance artefact to the people who share the space. The suggestion of the author is to fashion the scale to the physical footprint which is adhering to the footprint of other common objects that one would find in such a setting as a green house in an educational institution. One possible footprint would be that of a long table, whose dimensions are approximately 0,7m in width and 1 to 1,5m in length. That way the device could easily find its place in the room without disturbing those who use the space. One should also consider that it is always easier to fashion such a device with commercially available components such as water tanks and the like. Because the size and type of materials that would be available to the builder are unknown, only reasonable but arbitrary figures for the particulars of size will be given.. An example of a probable physical footprint of such a system is detailed in appendix 1. The device presented in appendix 1 is a table top which is 1 meter long and 0,7m wide giving an area 0,7m² and the filter/header tank unit stands 1 m high. It may be necessary to design the foot print and arrangement of components around the available materials as tanks of the particular dimensions and capacities outlined may not be commercially available. It is quite likely that a device of these proportions could fit easily in a large green house without bother. The above mentioned device has a capacity of 75 litres although its true capacity is 150 litres by the fact that the sand filter itself contains 75 litres. So if filter/header unit was totally empty one would have to put in 75 litres before any treated water could leave the filter.

6 Components

6.1 Basic process flow

In any system the order of process flow is better explained before the detailed description of components. In this system waste water from a sink is diverted from the sewer by a diversion valve in to a sump which is then pumped upwards to a header tank. The water is then fed through a sand filter and then hopefully hydrates some flora with relatively clean water. The water can then flow down the drain or be stored in another vessel or be cycled over again.

6.2 Sump

The sump is a pit or container at the lowest point of the system which catches the untreated grey water. In this system the position of the sump would be near the floor below the level of the redirection valve which is discussed in detail in chapter 6.3. The sump is the starting point of the treatment and reuse process and, if so configured, is also the last point of the process. Within the sump there is also a pump (see chapter 6.8) and this pump's purpose is to transfer the grey water to the header tank where gravity takes over the transfer of fluid and the treatment process begins. This pump also needs some input as to when to turn on and off, which can be achieved by a number of methods discussed more thoroughly in chapter 6.7. The size of the sump does not at first glance need to be in scale with the total volume of the system because if the sump's system of components (pump and control gear) is working correctly the waste water should be transferred quickly enough to the header vessel. The sump's paramount purpose is only to catch waste water and serve as a vessel in which the pump can draw from.

Also this sump is not complete without an overflow spout so that the water may drain away in to the sewer if for any reason that the pump does not engage. This is also pertinent in the case that a recirculation configuration is employed, that the system becomes over loaded with wastewater.

6.3 Redirection valve

The ability to select which waste water will be treated and what will be simply let drain into the sewer is an important feature for any grey water treatment system. Sometimes it is necessary to use and therefore dispose of harsh chemicals which would undoubtedly cause problems in any grey water treatment system. In order to have this functionality, a redirection valve needs to be present in this device. This type of valve is quite a simple component; however, a high level of quality of manufacture and materials should be ensured so to avoid any problems occurring.

The positioning of this valve is also an important consideration. Should this device only serve one sink in the TAMK greenhouse or could it be installed on the hub pipe of the drainage system (where all the sinks' water collectively drains in to the sewer). If this valve were positioned on a hub pipe, a greater chance of overly contaminated water entering the grey water treatment system is present. The reason is that if there are more sinks leading to the device there is a greater chance of someone disposing unsuitable chemicals without knowing or forgetting that one must divert that kind of waste to run directly into the sewer. It seems that this condition would be an eventual occurrence in a public learning environment where many people interact on a daily basis. It would perhaps be a more certain situation if the redirection valve only be installed on one sink's drain pipe. The device and sink could have signage advertising the particularities of the station (sink area) so that risk of transferring unsuitable waste water to the device would be effectively minimised because only one sink in the green house is applicable. These kinds of valves are not exotic components and there are a range of models by various manufactures. It would be also possible for an experienced handy man to fashion such a valve. But it is the opinion of the author that the easiest solution would be to simply purchase such a component, eliminating complications associated with manufacture. An example of this kind of valve is presented below of arbitrary manufacture (figure 1).

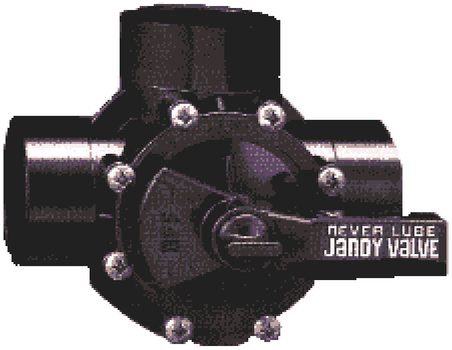


Figure 1: The Jandy never lube three port valve (Oasis Design 2008).

6.4.1 Vessels

If it is necessary to achieve the desired foot print of 0,7m,² which is roughly the area of a school table, there could be some problems as to finding commercially available vessels of the correct footprint dimensions. For instance the header vessel and filter assembly outlined in this thesis have the foot print of 0,5m L x 0,3mW x 0,5m H and a capacity of 75L each. This makes them rather tall containers and there is a tendency for commercially available containers of large capacities to be more broad than tall. Additionally having scoured the internet for suitable containers it turns out that large plastic containers also tend to be cylindrical which does not go along well with the proposed possible set up outlined in this thesis at all. Also most of the sites I found that did sell large containers were American, and they sold almost exclusively round containers. Surly there are some local sources of this type of product, apparently they do not sell them via the internet. If the American route in acquiring containers needs to be utilised, for future reference 20 gallons is roughly equivalent to 75L. Plastic containers would obviously be the most cost effective option for material and are commonly available as well as being of sufficient durability. If one must have the containers manufactured in order to achieve the desired foot print it is recommended that the chosen material is stainless steel. Stainless steel is not oxidising, very strong, durable and very common material for local engineers, whereas custom plastics are probably a less common craft. Stainless steel would of course cost more but if you are already having the vessel and filter manufactured by order, it would not arguably be less expensive to have it made from plastic.

6.4.2 Header vessel

The header vessel is the part which collects the waste water and distributes it linearly to subsequent components. Since this is the highest point of the device and as the name of the device suggest provides the hydraulic head to the whole device (Wikipedia 2009a). In fact if it were possible to position this component as well as subsequent components at a lower point than that of the redirection valve (see chapter 6.2), the pump (see chapter 6.8) could be eliminated and the device entirely gravity powered. It is, however, improbable that this design feature would be easily realised unless one were to position the grey water treatment device underground or on the next floor below. This could perhaps minimise the educational potential if the entire device were invisible.

The header vessel component could in theory be the largest capacity component of the entire system because it feeds the rest of the system. This capacity arises in the need for the device to have some kind of time retention ability in the delivery to other components. Therefore as well as a high capacity the drainage of waste water from the header vessel needs to be regulated. This regulation can be achieved quite simple by limiting the diameter of the opening or pipe which the waste water will flow out of the header vessel or by installing a variable flow valve at the point of exit. In some envisioned configurations of this device the header tank can also double or work in tandem with the sand filter; this aspect will be discussed more thoroughly in chapter 7.

6.5 Plant media

The plant media component is not a requirement to the system at all. That is, at least in the sense that it is not a necessary component of any waste water recycling system in which the main function of the plant media component is not to purify water but to serve as a structure to trap moisture in which plants can anchor themselves, grow and utilise the effluent. Though soil can be used as a filter and bio filter in which contaminated water can flow through and be treated in much the same way as a sand filter functions. This is because soil provides a structured medium in which biological organisms can flourish and also by the fact that it has small particle size and is therefore a filter if it is not too loosely packed. Of course in home systems the earth and mulch acts as a filter, however generally these systems which usually just divert water away from the sewer and in to the garden, the treated waste water is not collected but simply utilised by the plants in the garden. This is useful by the fact that fresh potable water is not wasted on organisms which do not require as high quality water as humans do.

The plant media/holder component in this device needs to be able to perform the exchange of fluids by it self. One of two methods of fluid exchange explained here is when the fluid actually enters the soil medium from the surface of the soil and seeps below and then out of that component. This particular set up strikes me with all kinds of problems which range from overflow to overly moistened soil in times of high flow. The second of these methods is where the fluid enters a semi hydroponic style planter box and flows from one end to the other. The plants receive moisture from proximity to water and the soil conveys it by capillary action. One such example of this type of semi hydroponic planter box is presented in appendix 3.

The planter box is really two trays one fitting inside the other. The outer tray is used to convey water through the component and control the height of the fluid. The inner tray has an array of holes in its bottom and holds the soil medium and plants. It would be recommended that a layer of gravel line the bottom of the soil tray in order to prevent the soil from eroding away into the fluid. This method allows plants which require a lot of moisture to grow their roots through the holes and dangle in the fluid itself.

6.5.1 Plants

When selecting the plants which are to be used in this system there are few considerations that should be understood. They should not be consumable plants as there are associated risks with consuming organisms that have gained nutrition from grey water (State of Victoria). Since at times the unit will run almost continuously is it a good idea that the plants be able to take prolonged periods of watering without detrimental effects. The unit can also be configured so that water is constantly running through the plant bed and thus simulates a wetland in some respects. So if we model this component on constructed wetlands we should in turn plant species which are common in constructed wetlands. Such species are cattail (*Typha latifolia*), planting reed (*Phragmites australis*), sedges, water hyacinth (*Eichhornia crassipes*) and *Pontederia* are used all over the world and are quite effective in the up take of metals. (Yeh, Chou & Pan 2009, 369.)

6.6 Sand filter

Sand filters are quite uncomplicated devices and their general principle of operation is simply to allow waste water to pass through an amount of sand so that suspended particles and bacteria become trapped in the sand (Water Treatment Plant 2009). There are three main types of sand filters; however, this work will concentrate mainly on the up flow type which is presented rather primitively below in chapter 6.6.2 figure 2. The three types are rapid (gravity) sand filter, the up flow sand filter and the slow sand filter (Water Treatment Plant 2009).

6.6.1 Rapid gravity sand filter

This filter is a type that is commonly used in municipal water treatment plants. They use quite course gravel and other granular material to remove particles and other impurities that have been trapped in flocs (a precipitation of suspended inorganic and organic contaminants by reacting the waste water with flocculation chemicals, usually ferric sulphate or aluminium sulphate) (Wikipedia 2009b). Because this type of filter requires flocculation chemicals it is deemed inappropriate for use in this device. Also this filter is commonly used in the final polishing process to produce potable water and in this system a high quality product as this is not required.

6.6.2 Up flow sand filter

In this filter style the water enters from below so that the maximum amount of contact between the water and sand is achieved. The method of producing this up flow is explained quite well by figure 2 below although in many systems this action is achieved by pressure. One advantage of this kind of filter is that it also provides a matrix for biological colonies to exist and contribute in the treatment process by consuming the pollutants as well as being a fine filter for trapping particles (Fenner 2008).

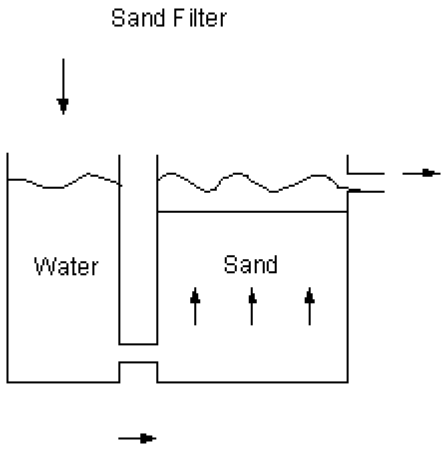


Figure 2: Diagram of up flow sand filter

One disadvantage of the filter shown in figure 2 is that the filtering begins as the water makes contact with the sand and in the case of figure 2 that is a rather narrow pipe or channel. This means clogging could become an issue in time. It would be a better option if the first layer of contact be of greater surface area so that the potential problem with clogging be minimised. An improved version of the up flow sand filter which has a greater surface area in the contact zone is presented in figure 3 below and in detail in appendix 2. Another obvious problem associated with such filters is that since the part of the sand which does most of the purifying is the sand in the contact zone (at the bottom), when it comes time to clean the filter, one must access the sand at the bottom of the filter which is the hardest to reach. Common washing procedures with this type of filter include backwashing and in large filter systems it is recommended to use air and water jets to clean the filters more rapidly (Fenner 2008). In the case of a system of this size simple intermittent backwashing and occasional manual replacement of the sand at least at the contact zone would be a requirement of effective operation.

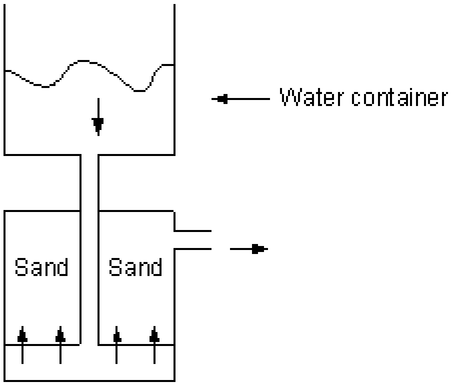


Figure 3: Improved up flow sand filter

6.6.3 Slow sand filter

Slow sand filters are used in water purification for treating raw surface water from dubious sources into a potable product. They are typically 1 to 2 meters deep and can be rectangular or cylindrical in cross section. The length and breadth of the filters are determined by the by the desired flow rate.

The principle of operation is that water seeps through a gelatinous layer (schmutzdecke) found in the top few millimetres of the fine sand filter called hypogeal layer. As water passes through the hypogeal layer, particles are trapped in the viscous matrix and dissolved organic material is absorbed and metabolised by bacteria, fungi and protozoa (Huismans & Wood 1974, 31). This type of filter is probably not suitable for use in the system in question because the slow flow rate could lead to an over flow to occur quite quickly, wasting most of the grey water.

6.6.4 Sand selection

When selecting the sand grain size to be used in the sand filter there are a couple of dynamic parameters which must be taken into consideration. Larger gain sizes have larger channels which decrease hydraulic retention time (HRT), in the case of a gravity fed down flow filter, and therefore minimises the filtration efficiency. Presumably the selected grain size needs to be small enough so that filtration is effective. Conversely the smaller the sand grain size the greater the propensity for clogging and under the condition of sand compaction HRT can be significantly reduced especially for down flow slow sand filters (Rolland, Molle, Liénard, Boudeldja & Grasmic 2009, 1006). The organic loading rate has a significant effect on clogging and performance of a filter (Siegrist 1987). It is thus recommended that a study be carried out to determine the average organic loading rate of the influent in respect to the volume of influent that is expected to occur. Oxygen values of coarse sand have been shown to remain stable whereas fine sand’s oxygen content tends to decrease overtime (Rolland *et al*. 2009, 1006). The available oxygen amount for aerobic micro organisms’ colony development could affect the filtering efficiency of the filter if the environment becomes too anoxic. The relationships between oxygen content and compaction over time are presented in figure 4. Where the fine sand diameter is 0.33mm and course sand is 0.8mm in diameter in slow down flow filter columns of surface area 0.1m^2 (Rolland et al. 2009, 1001). In light of this information it is recommended to use mainly course sand in order to promote aerobic colonies to flourish. However it is possible that the build up of biofilm which is generated by micro organisms may also lead to clogging. A careful balance between these parameters is needed to be established in order for optimisation of the maximum filtering vs. minimum maintenance relationship to be achieved. As these dynamic variables are dependant on the characteristics of the grey water influent, no definitive recommendation can be made here. Also common sense dictates that 5 to 10cm of pea gravel should be placed at the boundary zone of any grate surface to prevent material loss and the clogging of holes. (Rolland *et al*. 2009, 1000).

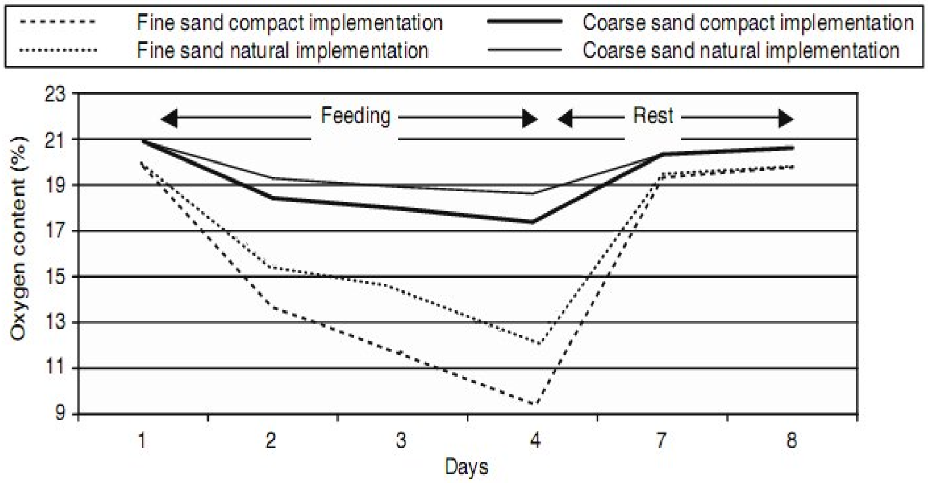


Figure 4: Oxygen profiles of sand types at 35cm under different compaction conditions after four weeks of feeding (Rolland *et* al. 2009, 1005).

6.7 Control systems

6.7.1 Pump activation systems

In this section any builders of said waste water treatment systems are faced with a choice when deciding what kind of pump activation system is necessary to achieve efficacy. In any case there are two main categories of pump activation components, the first being an array of water level sensors with a simple IC (integrated circuit) controller which would activate the pump when a predetermined water level condition is present. One might be tempted to spend good money on such a device; however, only rudimentary electronics knowledge will suffice if one attempts to construct a control circuit rather inexpensively themselves. The circuit diagram below (figure 5) is meant for 115V (American) line voltage but modifying it to be suitable for European voltages will no doubt stand in the way of anyone who enjoys this kind of activity. In any case the presence of the circuit diagram (figure 5) is only meant to exemplify how simple such a thing actually is. This circuit in figure 5 is designed to work with advanced water detection probes that monitor the presence of water by measuring conductivity.

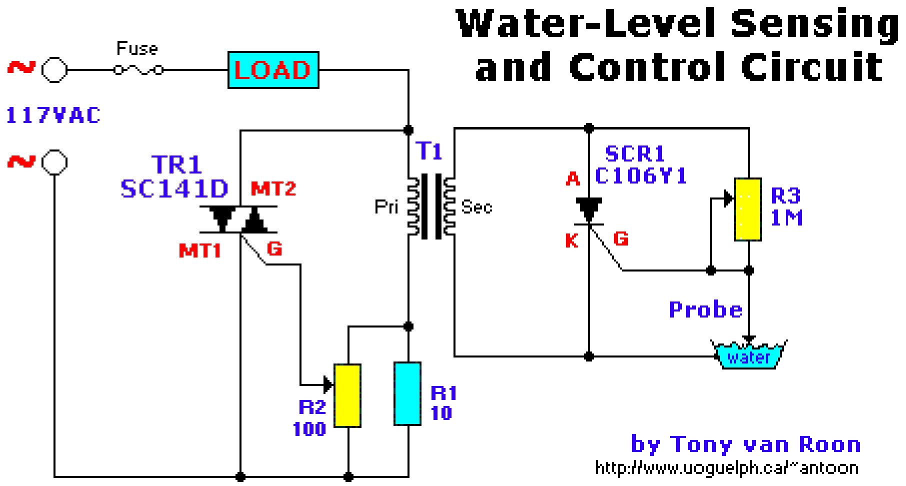


Figure 5: Circuit diagram for a water level sensing and control circuit (van Roon 1997).

<u>Parts list</u>

R1 = 10 ohm, 10 watt, wire wound
R2 = 100 ohm, potentiometer, wire wound
R3 = 1 Mega-ohm potentiometer
T1 = Transformer, 12.6volt, 1.2amp (min)
SCR1 = Silicon Controlled Rectifier, C106Y1, NTE5452, or equivalent
TR1 = TRIAC, SC141D, NTE5608, etc., rated 6-10 amp, 200-400 volt.TO-220.
Fuse = Slow-blow, 2 amp.

Another kind of pump activation system can be achieved by using float switches. Float switches are common in devices like toilet cisterns. In the example of the toilet cistern the water rises in the cistern when filling, as the water gets to a predetermined level a float (rigid flotation device) rises with the water as the float's buoyancy dictates, the float is connected to a rod which is connected to a valve on the inlet which stops the cistern from filling as it becomes full. This float's rod could just as easily be connected to an electrical micro switch in the system's sump which activates a pump. Another float switch can also be used to activate another micro switch to the off position as the sump becomes empty. Apparently this is perhaps the most common form of fluid level activation methods in use today (Wikipedia 2009c).

6.7.2 Flow rate control

In a system which treats water there is usually a need to prevent the water from flowing too quickly through the filter and or other components. This is especially true if there is a biological element to the treatment process. Depending on the configuration of the system the flow rate can be controlled very simply by having very precise diameter holes from which the water drains from the header vessel into the other subsequent components. This method will retain water and in components where this hole diameter management is used it is very necessary to have overflows which lead to the drain. But perhaps a more reliable solution would be to use a pump which can adjust the speed of pumping, it is better that the sump become overloaded rather than the header vessel so that the excess untreatable waste water can run directly into the drain at more or less the same elevation as the drain. This is only helpful to the extent that one needs not pump water into the header tank only to have it run all the way back to the drain. It is a question of energy efficiency only.

6.8 Pump

There are multitudes of pumping solutions available. The particulars of all the different kinds of pumps are numerous and could potentially be tiresome to outline both for the reader and the author. The purpose of a pump is to transfer a fluid to another location. The second location is often of a higher elevation than the source of the fluid. In the case of this grey water recycling system the purpose of the pump is to transfer grey water from the sump in to the header tank or directly to a filter if so configured. When selecting such a pump it is advised that the pump be of the type that has a variable output so that the tuning of the retention time can be realised in one component alone. A large aquarium pump will most likely be satisfactory for this type of application. Many pumps however do not like solids in the fluid so it is advisable that the pump have a quite fine strain filter fitted on the inlet of the pump.

7 Systems' configurations

When selecting the particulars of a grey water recycling system it is quite up to the choice of the designer in regard to the intended function of the system. One perhaps should start with a basic configuration such as is presented in figure 6 and add or remove functional components as the designer sees fit. There is no right way to structure such a waste water recycling system. However, with the previous sentence in mind, minimal functionality (purification and utilisation of grey water to some extent) should be achieved philosophically and practically speaking.

7.1 Basic configuration

All common components except for the sump/pump are shown in figure 6. This basic configuration is an easily achievable standard which can be referred to as needed. It is in essence what a laboratory scale device should look and function like under the assumption that the water is not intended for reuse by humans. In diagram figure 6 there is one extra component which has not been previously referred to, the storage tank at the bottom of the device. The storage tank obviously serves as a reservoir so that in the event that the volume of operation exceeds the volume of the device it self, there is an amount of stored water available which can be intended for a multitude of purposes. The designer may cycle this reservoir water back through the system by directing the overflow water into the sump or just let it drain back into the sewer. It is possible that this reservoir can serve as an aeration tank by adding an air source (aquarium air pump) so that this water is unable to become anaerobic even if it has been filtered.

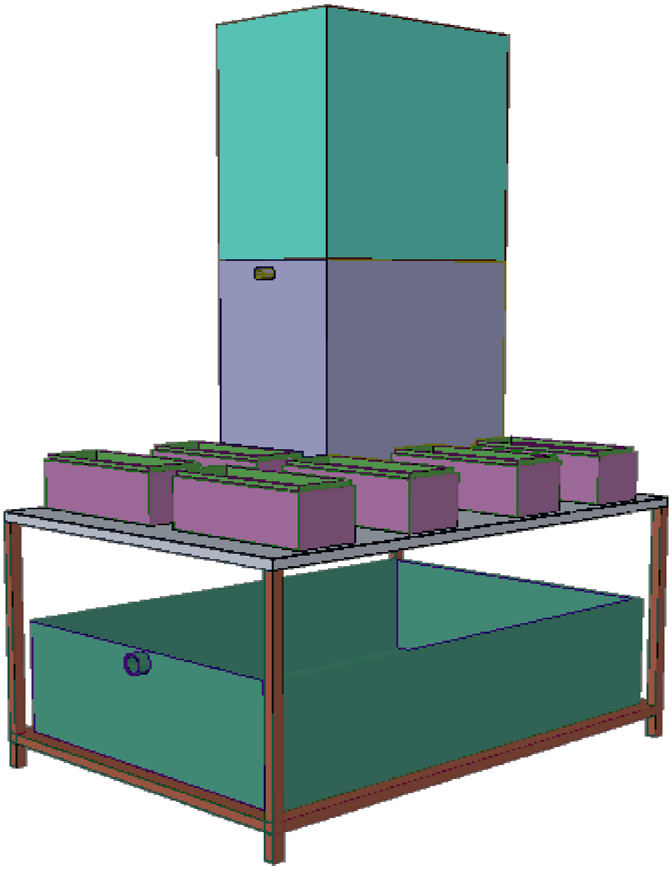


Figure 6: Whole grey water recycling system example.

7.2 Flow of waste water through components of basic configuration

The flow of waste water and treated water through components is presented in figure 8. Green pipes and hoses represent water which flows to the sewer from overflows and the drainpipe. Blue hoses represent water which flows internally in the system and whose locomotion is powered by gravity. The red pipe represents up flow waste water whose locomotion is powered by the pump. It is recommended to install a green overflow hose on the sump vessel to the sewer as well, for reasons of full proof operation, although it is not represented in figure 8 due to that particular area of the diagram becoming overly cluttered if that component were to be rendered. If one were to track the movement of water through the system linearly it would take the form of figure 7.

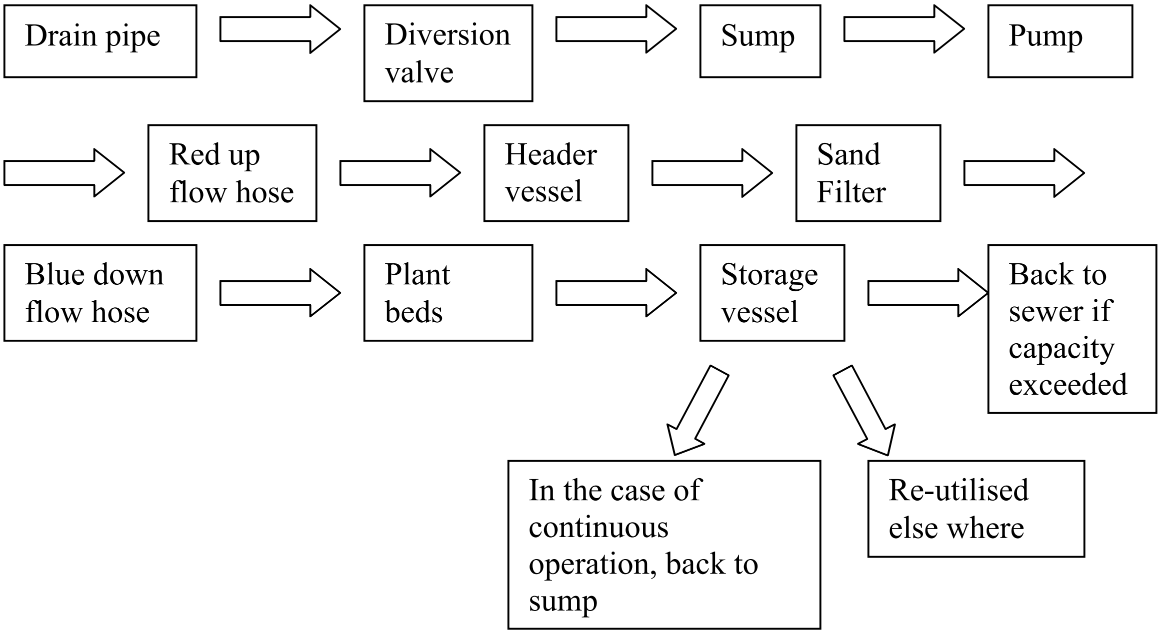


Figure 7: Process flow diagram of system in basic configuration.

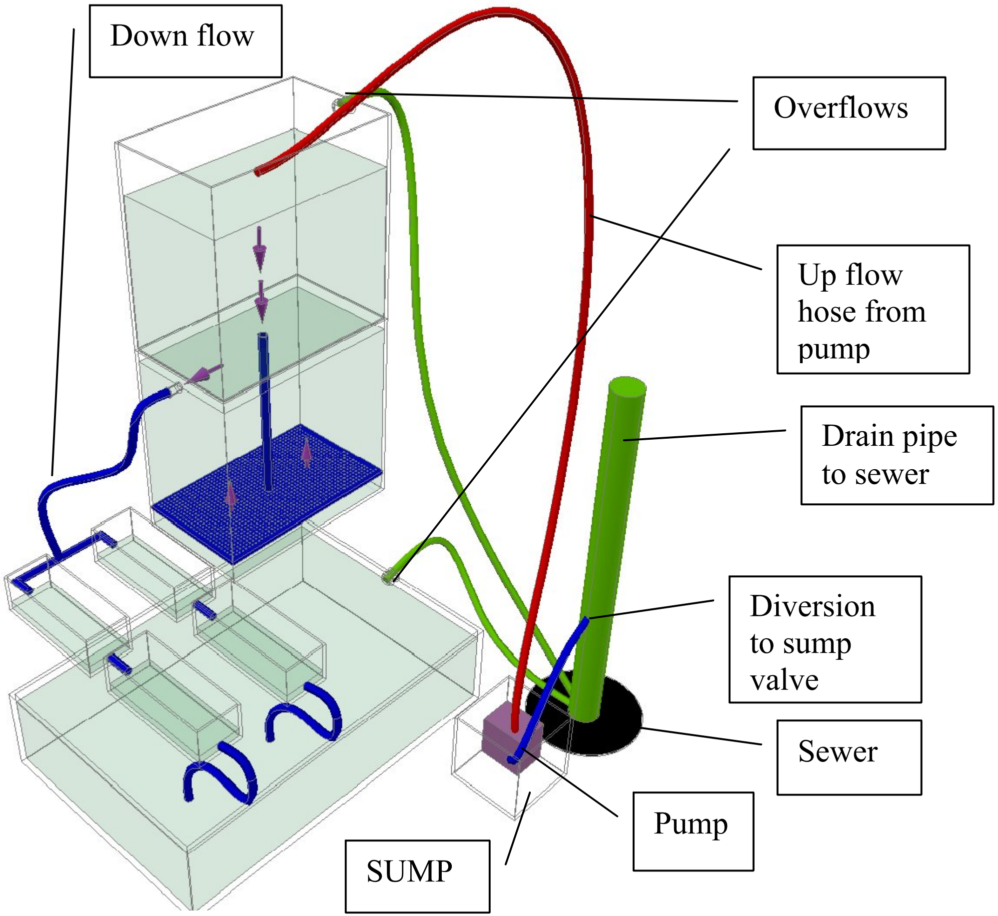


Figure 8: Graphical process flow diagram and tagged components.

In figure 9 the sand filter's process flow is outlined in detail. The sand and gravel layers have not been rendered in figure 9 for reasons of graphical clutter; however, a more detailed representation of the sand filter which includes sand and gravel layers is presented in appendix 2. In figure 9 the waste water enters from the top, flows down the central pipe of the grate component, flows through the grate separator and upwards towards the outlet, through the blue down flow hose to the plant beds. Another word of caution is that although the diagram seems to show that the filter and header tank are quite precisely placed on top of the other, there should under no circumstances be an air tight seal between the two surfaces at point X in figure 9, because that could lead to atmospheric pressure in the opposite direction, which would cause the waste water to cease flowing.

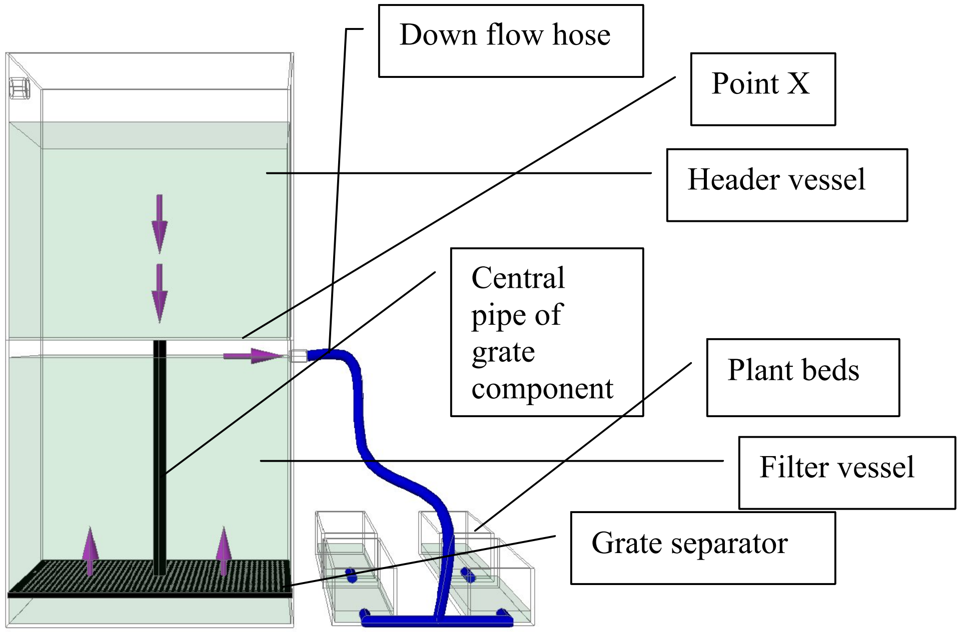


Figure 9: Graphical process flow of filter section.

7.3 Custom configurations

In the event that the designer needs to test or utilise some parameter of function he can do so by changing the order in which the waste water traditionally flows. For example some people would rather expose the plants to raw grey water because of the P and minimal N content. In this situation one would modify the basic configuration so that the sand filter would be positioned after the plants but before the reservoir.

If the designer requires the water to be reused by humans then they can add additional treatment component such as a slow sand filter or UV sterilisation unit. It is probably better that if a slow sand filter is used that it be positioned after a low out put device such as the plant beds rather than the header tank so that an over flow does not occur.

If there is not enough plants being watered then the designer could add more plant holder arrays to the system which can be connected and disconnected as needed. The capacity of the system can be increased or decreased by scaling up or down. When scaling the components one should always consider that the header tank should have less volume than the remaining components of the system so that overflows are unlikely to occur.

8 Conclusion

There are a lot of things to consider when designing a grey water recycling system but it is not so complex that it would be extremely difficult artefact to create. All the designer needs to do is first decide on the capabilities of the system and then carefully plan the system based on those intended capabilities. Those capabilities include

- footprint; how much floor space is suitable for such a device in a given environment
- volume; how much grey water can the system effectively treat
- purity of treated grey water; what level of purity is required for the intended end use
- level of technology; decide the level of sophistication required so that the system can effectively operate at the desired condition and how expensive the components can reasonably be
- expansion; is there a possibility that in the future more capacity is required

Using this thesis as a guide a designer/builder will have the necessary information to be able to create a simple grey water recycling system which can purify the grey water to the minimum extent that it is suitable for plant hydration.

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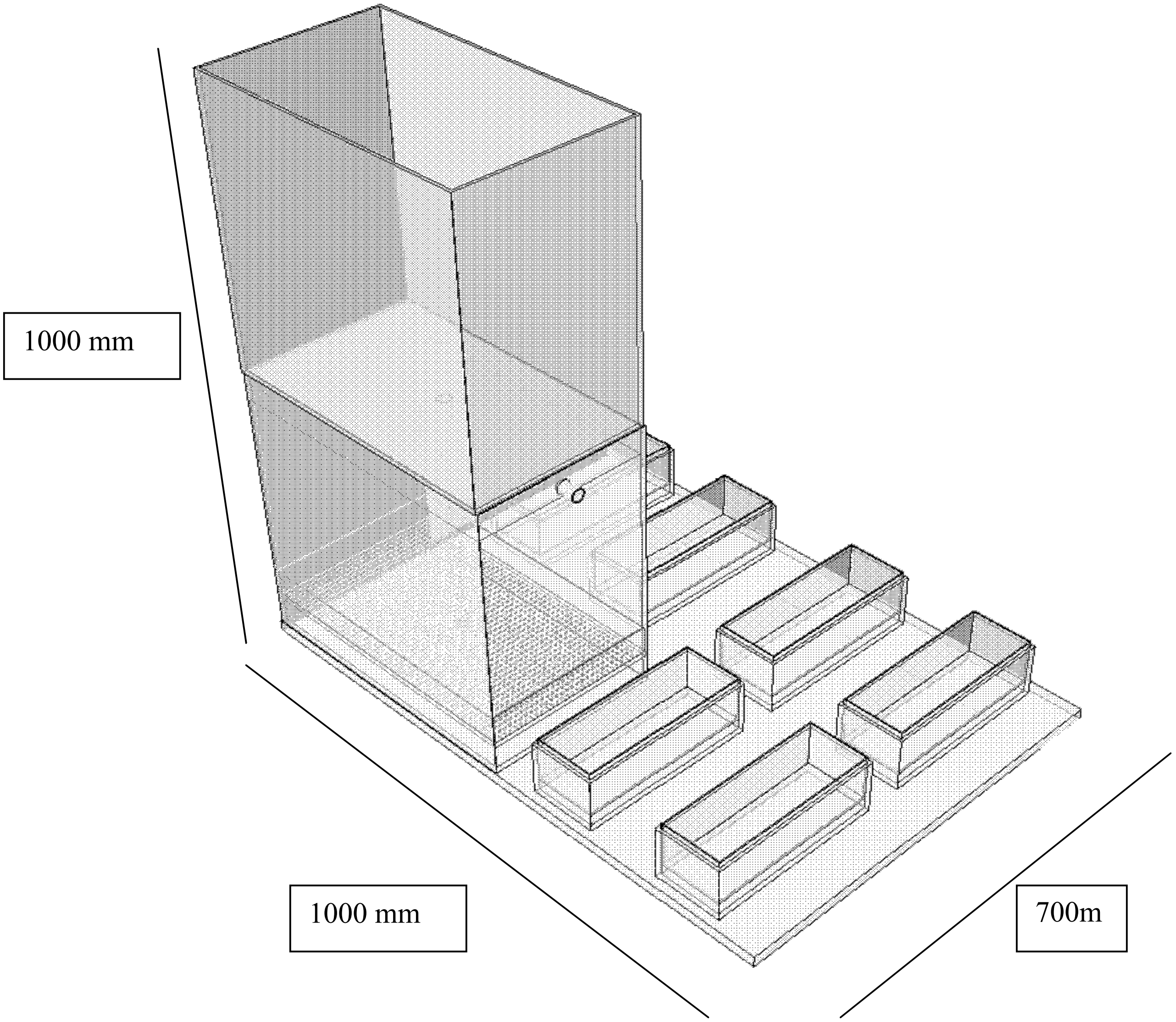
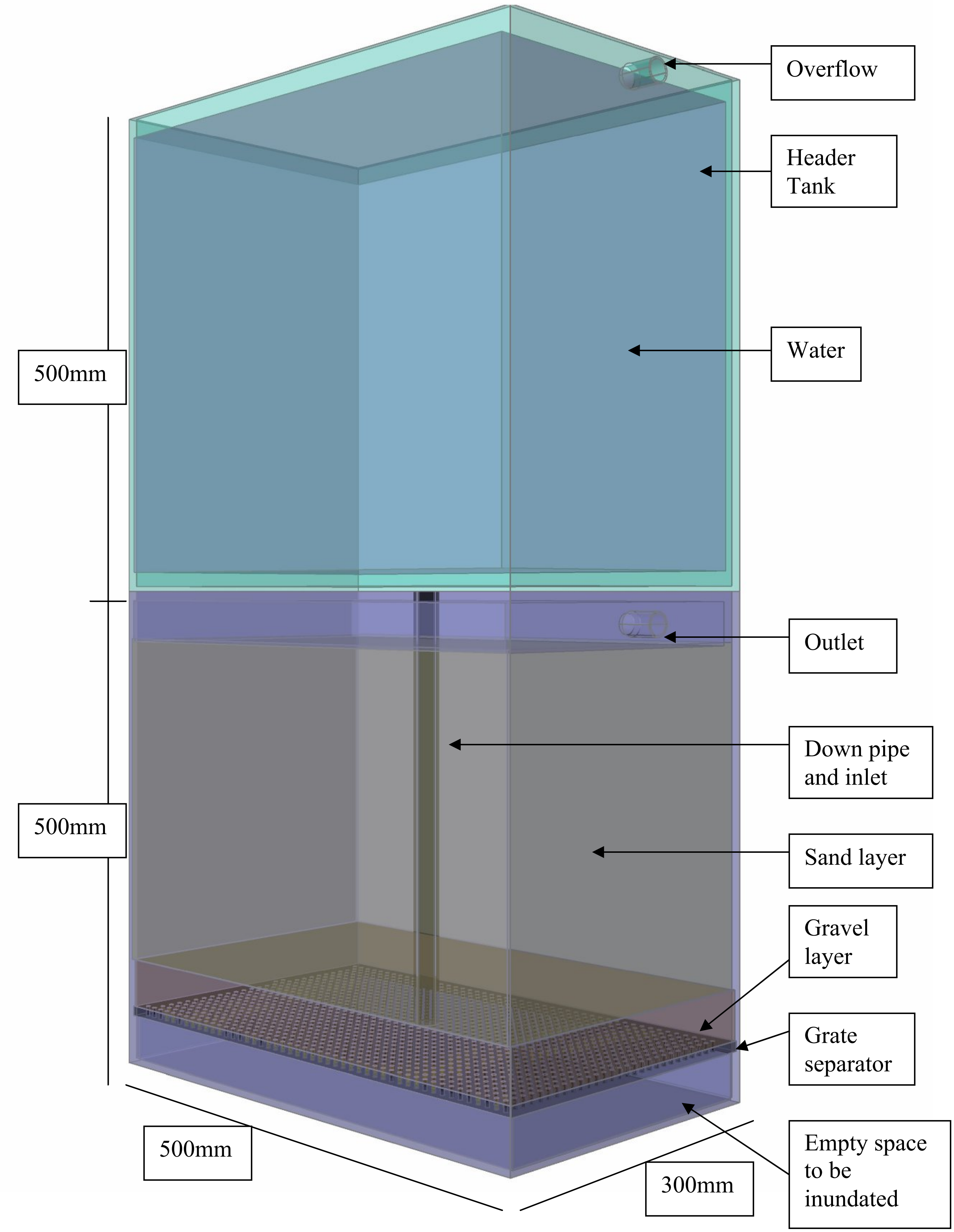
Appendices

Appendix 1: Foot print of possible grey water recycling system



Appendix 2: Parts and dimensions of up flow water filter of approximately 150 litres total capacity



Appendix 3: Semi hydroponic planter box