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Eidgenössische Technische Hochschule Zürich
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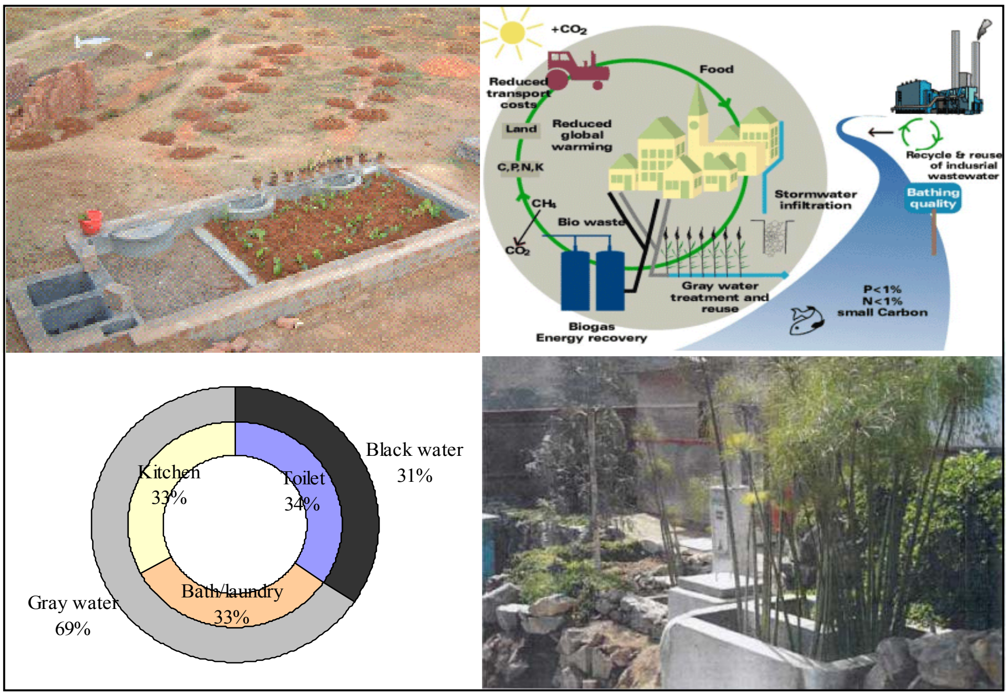
GREYWATER TREATMENT ON HOUSEHOLD LEVEL IN DEVELOPING COUNTRIES – A STATE OF THE ART REVIEW



SEMESTER WORK OF BARBARA IMHOF AND JOËLLE MÜHLEMANN

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SUPERVISOR: ANTOINE MOREL

References title page:
Picture top left: (Henry, 2004)
Picture top right: (Sarathai, 2004)
Picture down left: (Ledin et al., 2001b)
Picture down right: (SWO-docu, 2003)

Abstract

The issue of greywater management – which is defined as all sources of domestic wastewater excluding toilet wastewater – is gaining more and more importance, especially in developing countries where improper wastewater management is one of most important causes for environmental pollution and fatal diseases. In recent years not only the threats of improper greywater management have been recognised; there is an increasing international recognition that greywater reuse, if properly done, has a great potential as alternative water source for purposes such as irrigation, toilet flushing and others.

The main barrier for wider and faster dissemination of suitable greywater management systems on household level is the lack of knowledge and experience in that field, especially in developing countries. Scientific knowledge is sparse regarding greywater characteristics and adequate greywater treatment systems allowing a proper and safe disposal or reuse of greywater.

The main purpose of this report is to present the current state of the art regarding greywater management. The report presents typical greywater characteristics, the main treatment systems applied around the world and existing regulations for greywater treatment and reuse. Case studies are presented where greywater treatment systems are successfully applied.

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1 Introduction

In low-cost decentralised sanitation projects implemented in developing countries, the main focus is often put on latrine building, thus ignoring/neglecting the issue of greywater. If one wants to have comprehensive and sustainable decentralised sanitation projects with dry toilet systems one has to provide well functioning management systems for the greywater as well, otherwise the project will not have the expected impact on public health and environment. Proper greywater management, comprising collection, treatment and reuse or disposal, prevents humans of being in contact with it and limits pathogen transfer. A sound treatment also has positive effects on the nearby water bodies, since it limits the input of nutrients and thus eutrophication.

Greywater management is not only a precondition for clean and healthy living conditions, it also has a great potential for reuse. Treated greywater in a decentralised way is reused for a whole range of applications around the world; in developing countries, the reuse of treated greywater for irrigation purposes is most common.

In the past three decades, a great increase in the reuse of wastewater for agriculture purposes occurred, especially in semiarid areas. Several factors led to that trend (WHO, 1989a):

- the scarcity of alternative water sources for irrigation;
- the high cost of artificial fertilizer;
- the demonstration that risks and soil damage are minimal if the necessary; precautions are taken;
- the high cost of advanced wastewater treatment plants;
- the socio-cultural acceptance of the practice;
- the recognition by water resource planners of the value of the practice.

Greywater can be equated to traditional wastewater when it comes to compare the centralised to the decentralised approach to wastewater management. The motivations to treat wastewater in a decentralised way are diverse. Indeed, the decentralised approach (Morel and Koottatep, 2003):

- does not require large and capital intensive sewer trunks;
- broadens the variation of technological options;
- reduces the water requirements for waste transportation;
- is adaptable to different discharge requirements;
- reduces the risks associated with system failure;
- increases wastewater reuse opportunities;
- allows incremental development and investment of the system.

Therefore, the advantages of separate greywater treatment in decentralised systems are to shorten and close the water cycle, to prevent water shortage and to save money. The cycling of water occurs in a spatially limited area and the reuse of treated greywater takes place near the location where water was used initially. The reuse enables to prevent water shortage because precious and expensive water is saved. Greywater often contains valuable nutrients for gardening and irrigation and as a consequence there is no need to buy expensive mineral fertiliser. Another important fact is that people feel more responsible of their treatment system when it is decentralised and may pay more attention to the issue of greywater management.

The aim of this work was to provide an overview on the literature in the field of greywater treatment on household level in developing countries.

In chapter 2, greywater is defined. The current knowledge about the characteristics of greywater is summarised in chapter 3. The different treatment options and the legislation in different countries related to greywater treatment and reuse are resumed in chapter 4 and 5. Necessary considerations for planning treatment systems are given in chapter 6. In chapter 7, case studies of greywater management in developing countries are presented.
Finally, an attempt is made to propose further research in different domains of greywater reuse.

An integral part of this semester work is the End Note Database that was set up in the course of this literature review. The database compiles the most relevant publications in the field of greywater management.

2 Definition and terminology of greywater

2.1 Definition

There are several definitions for greywater in the literature. The biggest difference is whether kitchen wastewater is perceived as greywater or not. Table 1 gives an overview on definitions of greywater used in the literature.

Table 1: Definitions of greywater used in the literature

Definition	Kitchen included	References
Wastewater from baths, showers, hand basins, washing machines and dishwashers, laundries and kitchen sinks.	Yes	(Ledin et al., 2001a)
Wastewater without any input from toilets, which means it corresponds to wastewater produced in bathtubs, showers, hand basins, laundry machines and kitchen sinks, in households, office buildings, schools…	Yes	(Eriksson et al., 2002)
Wastewater excepting toilet wastes and food wastes derived from garbage grinders.	Partially	(Greywater.com, 2004)
Wastewater from washing machines, washing bowls, showers, bath tubes, cleaning containing mainly detergents	No	(Wilderer, 2003)
Wastewater without input from toilets (i.e. wastewater from laundries, showers, bathtubs, hand basins and kitchen sinks).	Yes	(Ottoson and Stenstrom, 2003)
Grey water arises from domestic washing operations. Sources include waste from hand basins, kitchen sinks and washing machines, but specifically exclude black water from toilets, bidets and urinals.	Yes	(Jefferson et al., 2001)
Graywater is defined as all wastewaters generated in the household, excluding toilet wastes. It can come from the sinks, showers, tubs, or washing machine of a home.	Yes	(Casanova et al., 2001)
Greywater is defined as all wastewater from non-toilet plumbing fixtures around the home. The use of kitchen greywater is not recommended as a greywater source.	No	(Christova Boal et al., 1996)
Grey wastewater (grey water) from bathrooms, washing machines and kitchen with little nutrients.	Yes	(Otterpohl et al., 1999)
Wastewater from buildings excluding that fraction discharged from the WC.	Yes	(Dixon et al., 1999)

Wastewater from washing, dish, bath water and the like.	Yes	(Gunther, 2000)
Wastewater from your laundry, bathtubs, showers, and bath sinks (lavatories). Water from kitchen sinks and dishwaters is not considered greywater.	No	(Little)
The domestic wastes from baths, showers, basins, laundries and kitchens specifically excluding water closet and urinal waste. Greywater does not normally contain human waste unless laundry tubs or basins are used to rinse soiled clothing or baby's napkins.	Yes	(Queensland, 2002) (Australian/ New Zealand Standard AS/NZS 1547: 2000 "On-site domestic wastewater management")
Graywater is washing water from bathtubs, showers, bathroom washbasins, clothes washing machines and laundry tubs, kitchen sinks and dishwashers.	Yes	(Del Porto and Steinfeld, 2000)
Greywater is wastewater which is not grossly contaminated by faeces or urine, i.e. the wastewater arising from plumbing fixtures not designed to receive human excrement or discharges and includes bath, shower, hand basin, laundry and kitchen discharges.	Yes	(NSWHealth, 2000)
Greywater is wastewater generated in the bathroom, laundry and kitchen, and is therefore the components of wastewater which have not originated from the toilet.	Yes	(Greywatersafer.com, 2004)

Wastewater from kitchen sinks and dish washing is sometimes excluded from greywater sources because of the potential to introduce microbial contaminants and/ or oils and greases that would negatively impact the receiving environment (TOWTRC, 2003). But in most sources kitchen wastewater is also contained in greywater.

2.2 Terminology

Several synonyms exist for the term greywater. The following list gives an overview on the expressions used. In this report the expression "Greywater" is used.

Table 2: Different expressions used for greywater

Expression	Definition	References
Grey water	British expression	(Jefferson et al., 2001) (Otterpohl et al., 1999)
Greywater	British expression	(Greywater.com, 2004) (Dixon et al., 1999) (Ottoson and Stenstrom, 2003) (NSWHealth, 2000) (Christova Boal et al., 1996) (Gunther, 2000) (Queensland, 2002) (Greywatersafer.com, 2004)

Grey wastewater	British expression	Used in: (Ledin et al., 2001a); (Eriksson et al., 2002) Mentioned in : (Otterpohl et al., 1999)
Gray water	American expression	(Wilderer, 2003)
Graywater	American expression	(Casanova et al., 2001) (Little) (Del Porto and Steinfeld, 2000)
Gray wastewater	American expression	No reference found
Sullage	Synonym for greywater	No reference found
Reclaimed water	Means every type of reused wastewater. More specific: Water from a municipal sewer system that has been treated and then delivered to high-volume water users such as golf courses, parks and playgrounds via a separate distribution system.	Defined in: (Little) Used in: (Crook and Surampalli, 1996) (Gregory et al., 1996)
Diluted wastewater	Synonym for greywater	Mentioned in: (Ledin et al., 2001a)
Light wastewater	Synonym for greywater	Mentioned in: (Ledin et al., 2001a)

In contrast, the expression blackwater includes every type of wastewater:
Toilet wastewater Synonym for blackwater (Greywater.com, 2004)

A further subdivision of wastewater types is also possible (Wilderer, 2003):

Brown water	Wastewater containing faeces
Yellow water	Wastewater containing urine
Black water	Wastewater containing both, faeces and urine
Gray water	Wastewater from washing machines, washing bowls, showers, bath tubes, cleaning containing mainly detergents
Green water	Wastewater from kitchen sinks containing mainly food particles
Storm water	Collected on roofs and driveways containing dust, hydrocarbons, abraded materials from rubber and break, and heavy metals from metallic roofs

3 Characteristics of greywater

A large compilation of data concerning physical and chemical characteristics of greywater was done by (Eriksson et al., 2002). Generally greywater is divided in four greywater-categories based on its origin: bathroom, laundry, kitchen and mixed origin. In this semester work the characteristics are based on the compilation of (Ledin et al., 2001a), which is not as extensive as (Eriksson et al., 2002), but partially uses the same sources, so giving the same ranges of values.

(Casanova et al., 2001) showed in their study about the *Casa del Agua* in Arizona that the overall microbial, chemical and physical quality of untreated household greywater lies somewhere between raw wastewater and secondary effluent.

3.1 Parameters affecting the characteristics of greywater

The composition of greywater depends on several factors, including sources and installations from where the water is drawn:

- quality and type of the water supply (groundwater well or piped water)
- type of distribution net for drinking water
- type of distribution net for greywater (because of leaching from piping, chemical and biological processes in the biofilm on the piping walls)
- activities in the household (lifestyle, custom and use of chemical products)
- installation from which greywater is drawn (kitchen sink, bathroom, hand basin or laundry wash)
- type of source: household or industrial uses like commercial laundries
- geographical location
- demographics and level of occupancy
- quantity of water used in relation to the discharged amount of substances

Greywater exhibits significant variations in composition; within a specific sample group, within an individual showering or bathing operation and also between reported schemes. The variation between the schemes reflects differences in washing habits both in terms of product type and concentration used by an individual. The relatively small scale of the majority of greywater schemes means that the variations seen from an individual can have a pronounced impact on the overall characteristics of the greywater to be treated (Jefferson et al., 2001). The composition of greywater also varies with time because of the variations in water consumption in relation to the discharged amount of substances.

An important effect has the chemical and biological degradation of the chemical compounds, within the transportation network and during storage. Chemical reactions can take place during storage and transportation of greywater, and thereby cause changes in the chemical composition of the water. Biological growth may lead to increased concentrations of microorganisms including faecal coliforms. This may also cause new organic and inorganic compounds to be produced as metabolites from partly degraded chemicals present in the greywater. The presence of nutrients such as phosphate, ammonium/ nitrate and organic matter will promote this microbial growth (Eriksson et al., 2002); (Ledin et al., 2001a).

The quintessence is that a large number of chemical compounds and microorganisms can be present in the greywater. The content of chemicals of a specific greywater can be based on the “declaration of contents” present on the packages of chemical products as well as on industrial production statistics (Ledin et al., 2001a); (Eriksson et al., 2002).

3.1.1 Water sources

Greywater can be divided into several groups, according to the source of the greywater. In this semester work the structure shown in table 3 is used. Table 3 gives a first overview of the general characteristics of the three main greywater source types.

Table 3: Summary of untreated greywater characteristics from each source (Queensland, 2002)

Water source	Characteristics
Laundry	*Microbiological:* variable thermotolerant coliform loads *Chemical:* sodium, phosphate, boron, surfactants, ammonia and nitrogen from soap powders and soiled clothes *Physical:* high in suspended solids, lint and turbidity *Biological:* high in biochemical oxygen demand (BOD)
Bathroom	*Microbiological:* lower levels of thermotolerant coliforms *Chemical:* soap, shampoo, hair dyes, toothpaste and cleaning chemicals *Physical:* high in suspended solids, hair, and turbidity *Biological:* lower levels of concentrations of biochemical oxygen demand
Kitchen	*Microbiological:* variable thermotolerant coliform loads *Chemical:* detergents, cleaning agents *Physical:* food particles, oils, fats, grease, turbidity *Biological:* high in biochemical oxygen demand

Normal use of products such as soap, shampoo, toothpaste, shaving cream, food scraps, cooking oils, dishwashing detergents, laundry detergents, hair and lint appears to do no harm to garden soils and plants if greywater is used for garden irrigation.
(Marshall, 1996)

The most significant pollutants of greywater are powdered laundry detergents. These contain high salt concentration and in many cases still contain phosphorus, and are often very alkaline. Long term garden reuse of laundry water containing high salt and phosphorus concentrations can lead to salt accumulations in the soil and stunting of plants with low phosphorus tolerance. Regions with regular rainfall may not suffer salt build-ups due to leaching of salts from soil after rain. There are several alternatives to using powdered laundry detergents. These include liquid detergents (which are generally much lower in salt content, e.g. Ark), pure soap flakes (e.g. Lux soap flakes) or ceramic disks (e.g. Tri-Clean laundry disks).
High strength cleaners should be avoided in the home, as they are often toxic to both people and the environment. If caustic cleaners are washed down the drain, they are likely to kill beneficial treatment bacteria in soils if greywater is reused for onsite garden irrigation (Marshall, 1996).

3.2 Chemical parameters

General features of greywater are that it contains lower concentrations of organic matter, of some nutrients (e.g. nitrogen, potassium) and microorganisms than blackwater.
But the concentrations of phosphorus, heavy metals and xenobiotic organic pollutants are around the same levels. The main sources for these pollutants are chemical products such as laundry detergents, soap, shampoo, toothpaste and solvents.

3.2.1 General hydrochemical parameters

The content of biological oxygen demand (BOD) and chemical oxygen demand (COD) indicates the risk of oxygen depletion due to the degradation of organic matter during transport and storing and the risk of sulphide production, causing bad smell (Ledin et al., 2001a).

In contradiction to (Ledin et al., 2001a), (Eriksson et al., 2002) state that most of the COD derives from household chemicals like dishwashing and laundry detergent, so that COD in greywater is expected to be at the same levels as the COD in household wastewater.

Table 4: Measured values of general hydrochemical parameters and standard wastewater parameters in greywater (Ledin et al., 2001a)

Chemical properties	Laundry	Bathroom	Kitchen sink
pH	9.3- 10[A]	5- 8.1[A, B, D, E]	6.3- 7.4[F]
EC [µS/cm]	190- 1400[A]	82- 20'000[AD]	
Alkalinity [mg/l]	83- 200 as $CaCO_3$[A]	24- 136 as $CaCO_3$[A, E]	20.0- 340.0[F]
Hardness [mg/l]	-	18- 52 as $CaCO_3$[E]	-
BOD_5 [mg/l]	48-380[A, C]	76- 200[A]	-
BOD_7 [mg/l]	150[G]	170[G]	387- 1000[G]
COD [mg/l]	375[G]	280[G] up to 8000 COD_{Cr}	26- 1600[F, G]
TOC [mg/l]	100-280[C]	15- 225[E]	-
Dissolved oxygen [mg/l]	-	0.4- 4.6[D]	2.2- 5.8[F]
Sulfate [mg/l]	-	12- 40[B]	-
Chloride (as Cl) [mg/l]	9.0-88[A]	3.1- 18[A, B]	-
Oil and grease [mg/l]	8.0-35[A]	37- 78[A]	-

A, (Christova Boal et al., 1996); B, (Rose et al., 1991); C, (Siegrist et al., 1976); D, (Santala et al., 1998); E, (Burrows et al., 1991); F, (Shin et al., 1998); G, (Hargelius et al., 1995)

3.2.2 Nutrients in greywater

Washing detergents are the primary source of phosphates found in greywater in countries that have not yet banned phosphorus-containing detergents (Eriksson et al., 2002).

According to (Gunther, 2000), greywater has a typical N/P ratio of 2, thus far below the N/P ratio of around 10 which would be optimal for nutrient uptake by plants. This is very important if greywater is reused for irrigation. Nitrogen then represents the limiting substance, leading to a sub-optimal phosphorus uptake unless the plants can get nitrogen from other sources.

Table 5: Measured values of nutrients in greywater (Ledin et al., 2001a)

Nutrients [mg/l]	Laundry	Bathroom	Kitchen sink
Ammonia (NH_3-N)	< 0.1- 3.47[A, B, C, G]	<0.1- 25[A, B, D, G]	0.2- 23.0[F, G]
Nitrate and nitrite as N*	0.10- 0.31[A]	<0.05- 0.20[A]	-
Nitrate (NO_3-N)	0.4- 0.6[C]	0- 4.9[B]	-
Phosphorus as PO_4	4.0- 15[C]	4- 35[B, D]	0.4- 4.7[F]
Nitrogen as total	1.0- 40[A]	4.6- 20[A]	15.4- 42.8[F]
Tot- N	6- 21[C, G]	0.6- 7.3[B, G]	13- 60[G]
Tot- P	0.062- 57[A, C, G]	0.11- 2.2[A, G]	3.1- 10[G]

*** = per 100ml; for abbreviations, see table 4**

3.2.3 Ground elements in greywater

Laundry wastewater was found to contain elevated sodium levels compared to other types of greywater. The sodium in the laundry wastewater may be caused by the use of sodium as counterion to several anionic surfactants used in powder laundry detergent and the use of sodium chloride in ion-exchangers (Eriksson et al., 2002).

Products containing boron should be avoided as it is toxic to plants even in small amounts (Marshall, 1996).

Table 6: Measured values of ground elements in greywater (Ledin et al., 2001a)

Ground elements [µg/l]	Laundry	Bathroom	Kitchen sink
Aluminium (Al)	<0.1- 21[A]	<1.0[A]- 1.7[G]	0.67- 1.8[G]
Barium (Ba)	0.019[G]	0.032[G]	0.018- 0.028[G]
Boron (B)	<0.1- 0.5[A]	<0.1[A]	
Calcium (Ca)	3.9- 14[A, G]	3.5- 21[A, G]	13- 30[G]
Magnesium (Mg)	1.1- 3.1[A, G]	1.4- 6.6[A, G]	3.3- 7.3[G]
Potassium (K)	1.1- 17[A, G]	1.5- 6.6[A, G]	19- 59[G]
Selenium (Se)	<0.001[A]	<0.001[A]	
Silicon (Si)	3.8- 49[A]	3.2- 4.1[A]	
Sodium (Na)	44- 480[A, G]	7.4- 21[A, G]	29- 180[G]
Sulphur (S)	9.5- 40[A]	0.14- 3.3[A, G]	0.12

3.2.4 Heavy metals in greywater

Plastic and metal piping both release compounds, such as XOCs and heavy metals, to the water supply and to the greywater. The contents in greywater are dependent from three sources (Ledin et al., 2001a):

- Chemical products, resulting from water use
- The type of pipes used for transportation
- The quality of the water supply when it leaves the water works

Table 7: Measured values of heavy metals in greywater (Ledin et al., 2001a)

Heavy metals [µg/l]	Laundry	Bathroom	Kitchen sink
Arsenic (As)	0.001- <0.038[A, G]	0.001[A]- <0.0038[G]	<0.038[G]
Cadmium (Cd)	<0.01- <0.038[A, G]	<0.01[A, G]	<0.007[G]
Chromium (Cr)	<0.025[G]	0.036[G]	<0.025- 0.072[G]
Cobalt (Co)	<0.012[G]	<0.012[G]	<0.013[G]
Copper (Cu)	<0.05- 0.27[A, G]	0.06- 0.12[A, G]	0.068- 0.26[G]
Iron (Fe)	0.29- 1.0[A, G]	0.34- 1.4[A, G]	0.6- 1.2[G]
Lead (Pb)	<0.063[G]	<0.063[G]	<0.062- 0.14[G]
Manganese (Mg)	0.029[G]	0.061[G]	0.031- 0.075[G]
Mercury (Hg)	0.0029[G]	<0.0003[G]	<0.0003- 0.00047[G]
Nickel (Ni)	<0.025[G]	<0.025[G]	<0.025[G]
Silver (Ag)	0.002[G]	<0.002[G]	<0.002- 0.013[G]
Zinc (Zn)	0.09- 0.44[A, G]	0.01- 6.3[A, G]	0.0007- 1.8[G]

3.2.5 Xenobiotic organic compounds (XOC) in greywater

The XOCs that could be expected to be present in greywater constitute a heterogeneous group of compounds. They originate from the chemical products used in households such as detergents, soaps, shampoos, perfumes, preservatives, dyes and cleaners. Kitchen wastewater contains lipids (fats and oils), tea, coffee, soluble starch, diary products and glucose, while the wastewater produced from laundry will contain different types of detergents, bleaches and perfumes (Eriksson et al., 2002).
The long chained fatty acids are originating from soap.

Table 8: Measured values of xenobiotic organic compounds (XOCs) in greywater (Ledin et al., 2001a)

Xenobiotic organic compounds	Laundry	Bathroom	Kitchen sink
Detergents		Identified[D]	
Long chained fatty acids		Identified[E]	

Identified = only qualitative analyses, no quantifications were performed

These results are not representative for the XOCs present in greywater. Thousands of different compounds have been mentioned in the literature and for combined wastewater at least 500 different XOCs have been identified and quantified. For greywater it could be showed that at least 900 different substances or groups of substances could be present in it, due to the use of chemical household products. The study conducted by (Eriksson et al., 2002) was largely based on the information available in the declaration of contents present on the different types of common household products, covering products from shampoo and toothpaste to washing powders. The major compounds were surfactants used in detergents, dishwashing liquids and hygiene products. Other large groups were solvents and preservatives.
(Eriksson et al., 2002) applied a method that usually is employed in environmental risk assessment of new chemical compounds. A classification of the XOCs was made based on data about toxicity, bioaccumulation and biodegradation. 8 different groups identify how environmentally hazardous the compounds are estimated to be. Of the approximately 900 substances identified as being potentially present in household chemicals, 10% were categorised as priority pollutants. For detailed information see (Eriksson et al., 2002).

3.3 Physical parameters

- Temperature
  Greywater temperatures are often higher than the temperature of the water supply due to hot tap water used for personal hygiene and laundry.
  High temperature favours microbial growth and leads to precipitation of e.g. calcite in supersaturated waters (Eriksson et al., 2002).
- Colour
- Turbidity
- Content of suspended solids
  The measurements of turbidity and suspended solids give information about the content of particles and colloids that could cause clogging of soil pores and installations. Generally highest values are found in greywater generated in kitchen sinks and washing machines.

Table 9: Physical properties of greywater (Ledin et al., 2001a)

Physical properties [mg/l]	Laundry	Bathroom	Kitchen sink
Colour (Pt/Co units)	50-70[A]	60- 100[A]	
Suspended solids	79- 280[A, C, G]	48- 120[A, G]	134-1300[F, G]
TDS		126-175[E]	
Turbidity [NTU]	14-296[A, B, C]	20- 370[A, B, E]	
Temperature [°C]	28- 32	18-38[D]	

3.4 Microbiological parameters

Generally there is very little known about the presence of microorganisms in greywater. Four types of pathogens may be present: viruses, bacteria, protozoa and intestinal parasites (helminths). It can, however, be expected, when evaluating microbiological parameters, that microbial populations of faecal origin in greywater cause the major health risk(Ledin et al., 2001a).

3.4.1 Organisms possibly present in greywater

Pathogenic viruses, bacteria, protozoa and helminths (Helminth: Worm that is parasitic on the intestines of vertebrates especially roundworms and tapeworms and flukes; www.cogsci.princeton.edu/cgi-bin/webwn) escape from the bodies of infected persons in their excreta and may be passed onto others via exposure of wastewater.
These microorganisms may be introduced into greywater by hand-washing after using the toilet or changing nappies, baths, washing babies and small children, and from uncooked food products in the kitchen. A list of pathogenic microorganisms potentially present in greywater is given in table 10 (Eriksson et al., 2002).

The available evidence indicates that almost all excreted pathogens can survive in soil and ponds for a sufficient length of time to pose potential risks to farm and pond workers (See table 10). Pathogen survival on crop surfaces is much shorter than that in soil, as the pathogens are less well protected from the harsh effects of sunlight and desiccation. In some cases, however, survival times can be long enough to pose potential risks to crop handlers and consumers, especially when they exceed the length of crop (mainly vegetable) growing cycles (WHO, 1989b).

Table 10: List of pathogenic water and excreta-related microorganisms found to be present in different types of waters including wastewaters (Eriksson et al., 2002). Survival times of pathogens in warm climates (20-30°C) (WHO, 1989b)

Bacteria	Survival time (days) in soil	Survival time (days) on crops
Bacteroides fragilis		
Bifidobacterium adolescentis		
Bifidobacterium longum		
Campylobacter jejuni		
Clostridium perfringens		
E. coli		
Eubacterium spp.		
Faecal coliforms	<70 but usually <20	<30 but usually <15
Helicobacter pylori		
Lactobacilli		

Legionella pneumophilia		
Leptospira		
Peptococcus spp.		
Peptostreptococcus spp.		
Pseudomonas aeruginosa		
Salmonella typhi	<70 but usually <20	<30 but usually <15
S. paratyphi	<70 but usually <20	<30 but usually <15
Other salmonellae	<70 but usually <20	<30 but usually <15
Shigella sonnei		
Other shigella		
Streptococcus bovis		
S. durans		
S. equines		
S. faecalis		
S. faecium		
Vibrio cholerae	<20 but usually <10	<5 but usually <2
Other vibrios		
Yersinia enterocolitica		
Protozoa		
Balantidium coli		
Cryptosporidium parvum		
Cyclospora cayetanenis	(cysts) <20 but usually <10	(cysts) <10 but usually <2
Encephalitozoon hellem		
Entamoeba histolytica		
Enterocytozoon bienusi		
Giardia lamblia		
Neagleria		
Helminths		
Ancylostoma duodenale		
Necator americanius		
Ascaris lumbricoides	(eggs) many months	(eggs) <60 but usually <30
Clonorchis sinensis		
Diphyllobothrium latum		
Enterobius vermicularis		
Fasciola hepatica		
Fasciolopsis buski		
Gastrodiscoides hominis		
Heterophyes heterophyes		
Hookworm larvae*	<90 but usually <30	<30 but usually <10
Hymenolepsis spp.		
Metagonimus yokogawai		
Optisthorchis felineus		
O. viverrini		
Paragonimus westermani		
Schistosoma haematobium		
S. japonicum		
S. mansoni		
Strongyloides stercoralis		
Taenia saginata	(eggs) many months	(eggs) <60 but usually <30
T. solium		

Trichuris trichiura	(eggs) many months	(eggs) <60 but usually <30
Viruses		
Adenoviruses		
Coxsackieviruses	<100 but usually <20	<60 but usually <15
Echoviruses	<100 but usually <20	<60 but usually <15
Hepatitis A virus		
H. E virus		
H. F virus		
Polioviruses	<100 but usually <20	<60 but usually <15
Reoviruses		
Rotaviruses		

*** = Mentioned in (WHO, 1989b) but not in (Eriksson et al., 2002)**

The following table 11 gives the value ranges of microbiological parameters usually found in greywater.

Table 11: Measured values of microbiological parameters in greywater (Ledin et al., 2001a)

Microbiological parameters	Laundry	Bathroom	Kitchen sink
Campylobacter spp.	n.d[A]	n.d[A]	
Candida albicans		n.d[E]	
Colifager PFU/ml	102 x 10^{3} [G]	388 x 10^{3} [G]	<3[G]
Cryptosporidia	n.d[A]	n.d[A]	
*Eschericia coli**	8.3 x 10^{6} [G]	3.2 x 10^{7} [G]	1.3 x 10^{5} – 2.5 x 10^{8} [G]
Faecal coliforms*	9- 1.6 x 10^{4} [A, B, C]	1- 8 x 10^{6} [A, B, C]	
Faecal streptococci*	23- 1.3 x 10^{6} [A, B, C, G]	1- 5.4 x 10^{6} [A, C, G]	5.15 x 10^{3} – 5.5 x 10^{8} [G]
Giardia	n.d[A]	n.d[A]	
Heterotrophic bacteria*		Up to 1.8 x 10^{6} [D]	
Pseudomonas aeruginosa		n.d[E]	
Salmonella spp.	n.d[A]	n.d[A]	
*Staphylococcus aureus***		1- 5 x 10^{5} [E]	
Thermotolerant coli*	8.4 x 10^{6} [G]	Up to 8.9 x 10^{6} [D, G]	0.2 x 10^{6} – 3.75 x 10^{8} [G]
Total coliform*	56- 8.9 x 10^{5} [A, B, C]	70- 2.8 x 10^{7} [A, B, C, E]	
Total bacterial population (cfu/100ml)		300- 6.4 x 10^{8} [E, B]	

*** = per 100ml; ** = per ml**

If the greywater is reused for irrigation, parasitic protozoa and helminths will not be a problem in relation to groundwater contamination due to their large size, which results in their removal by filtration as the water percolates under gravity (Eriksson et al., 2002). Bacteria and virus contamination of groundwater may, on the other hand, be a serious problem.

Organisms that are relatively resistant to disinfection will prevail longer within the system i.e. *Cryptosporidium* and *Giardia* (protozoa). *Clostridium perfringens* (protozoa) spreads by spores and can survive longer than most other microorganisms. The spores can be used as indicators of cumulative faecal contamination.
Many species of helminths can infect humans but they cannot multiply within the host, with the exception of *Strongyloides*. *Legionella* poses a specific threat since it can be spread by aerosols and can be inhaled during surface irrigation or toilet flushing. Due to the fact that it is resistant to water treatment processes, it can become a serious problem (Dixon et al., 1999).
Although urine should not be present, it has been noticed that, from time to time, traces of urine are present in greywater from bathrooms. Urine is generally sterile and harmless but some infections may cause pathogens to be passed into the urine. The three principal infections are urinary schistosomiasis (*Schistosoma haematobium*), typhoid (*Salmonella typhi*) and leptospirosis *(Leptospira*) (Eriksson et al., 2002).

3.4.2 Indicator organisms

Bacterial indicator growth, particularly of the coliform group, may occur in the system overestimating the faecal load of greywater substantially. Of the bacterial indicators, faecal enterococci seem to be the most appropriate to use since the overestimation of the faecal load is not as high as for the use of coliform bacteria, although they also seem to have the ability to re-grow within a greywater system. Another way to measure the faecal contamination is by using chemical biomarkers, like coprostanol. But this measurement may also have some limitations, underestimating the risk in systems to which many infants are connected (Eriksson et al., 2002).

In conclusion it is suggested that guidelines for greywater reuse should not be based on thermotolerant coliforms as a hygienic parameter, because of the large input of non-faecal coliforms and/or growth of coliforms. The overestimation of the faecal load, and thus risk, that the indicator bacteria give is however to some degree compensated for by the higher susceptibility to treatment and environmental die-off (Ottoson and Stenstrom, 2003).

3.4.3 Minimisation of risk

Disease transmission by greywater occurs by direct ingestion (e.g. through contaminated hands) or by indirect ingestions through contact with contaminated items such as grass, soil, garden implements and treatment plants while they are being serviced. Transmission may also occur through inhalation of spray irrigation, by penetration through broken skin, and by insect vectors such as flies and cockroaches (Queensland, 2002).

The health risk posed by untreated greywater can never be eliminated, however it can be minimised by appropriate treatment, careful management and responsible use. This may be achieved by (Queensland, 2002):

- separating potentially contaminated nappies and clothes;
- never drinking greywater or allowing pets or animals to drink or have access to it;
- ensuring greywater does not contaminate any source of drinking water: e.g. drinking water aquifer;
- applying greywater to the garden by subsurface irrigation. This will reduce human exposure to the water;
- by not irrigating vegetable gardens supplying food crops that are eaten raw or undercooked as this would pose an unacceptable health risk;

- not allowing greywater to pool or stagnate as this will attract insects and rodents that may transmit disease;
- always washing hands after gardening.

3.5 Comparison with ordinary domestic wastewater

One of the most significant differences between blackwater and greywater lies in the rate of decay of the pollutants in each. Greywater decomposes much faster than blackwater. Because of its rapid decomposition rate, greywater discharged into a stream or lake will have a more immediate impact on the recipient body of water at the point of discharge than combined wastewater. However, for the same reason, greywater will decompose faster in soils after infiltration and does not travel to pollute nearby drinking water nearly as much as do combined wastewater or blackwater discharge (Greywater.com, 2004).

Another big difference is the content of nitrogen (see table 12). Greywater contains only about one-tenth of the nitrogen contained in blackwater. Furthermore, the nitrogen found in greywater is around half the organic nitrogen (i.e. tied to organic matter) and can be filtered out and used by plants (Greywater.com, 2004).

The Internet Page Greywater.com was the only source that mentioned those two differences. The overall impression of the page was that it gave valuable information, but one should be critical about how scientific it is.

Table 12: Comparison of average pollutants load between greywater and combined grey- and blackwater ((Greywater.com, 2004), data compiled by Dr. Margaret Findley from five studies

Type	Greywater [g/person/day]	Grey- and Blackwater combined[g/person/day]
BOD_5	34	71
SS	18	70
Total N	1.6	13.2
Total P	3.1	4.6
Total P*	0.5	1.9

*** = No phosphorus detergent**

Table 13: Comparison between greywater and household wastewater, based on data from (Ledin et al., 2001a)

Type [mg/l]	Greywater Laundry	Greywater Bathroom	Greywater Kitchen sink	Household wastewater
COD	375^{G}	280^{G} up to 8000 COD_{Cr}	26- $1600^{F, G}$	210- 740^{H}
BOD	48- $380^{A, C}$ BOD_5	76- 200^{A} BOD_5		150- 530^{H}
Nitrogen	6- $21^{C, G}$	0.6- $7.3^{B, G}$	13- 60^{G}	20- 80^{H}

H: (Henze et al., 2000), (Henze and Ledin, 2001)

Greywater has lower COD and BOD contents, because faecal matter and toilet paper are not present in greywater and because more water is used for the production of greywater than for combined wastewater (Ledin et al., 2001a).

Greywater can have an organic strength (in terms of BOD and COD) similar to domestic wastewater but greywater is relatively low in solids suggesting that a greater fraction of the organic load is dissolved. Although the concentration can be similar to domestic wastewater the composition is not. The COD:BOD ration can be as high as 4:1 with a corresponding deficiency in macronutrients such as nitrogen and phosphorus (Jefferson et al., 2001).

The lower values for nitrogen are explained by the absence of urine in the greywater. The values for P are also relatively low. The lower ranges for both nutrients indicate that the risk of eutrophication of receiving waters is lower than fore combined wastewater (Ledin et al., 2001a).

3.6 Amounts produced

Table 14: Compilation of information about amounts of greywater produced

Amount	Location of investigation	References
73 % of the volume of combined residential sewage	Moderate climate, industrialized country	(Hansen and Kjellerup, 1994) Cited in: (Ledin et al., 2001a) (Eriksson et al., 2002)
30% of the total water use of a household		(Jefferson et al., 2001)
65 l/person/day	Housing area in Stockholm	(Ottoson and Stenstrom, 2003)
5% of average household water consumption is produced in the kitchen; 26% in hand basins, showers and bathroom; 15% in laundry troughs and washing machines and 20% in the toilet	Melbourne, Australia	(Christova Boal et al., 1996)
123 l/person/day	Tucson, Arizona	(Casanova et al., 2001)
< 50 % of the volume of combined residential sewage	Arid regions	(WHO, 1989b)
75.7 – 132.5 l/person/day	Arizona, USA	(Little)
586 l/ day in three-bedroom dwelling	Brisbane	(Queensland, 2002)
50- 80% of all combined residential effluent volume (sewage)		(Del Porto and Steinfeld, 2000)
125 l/person/day	Massachusetts	(Del Porto and Steinfeld, 2000)
68% of total wastewater stream	Industrial	(NSWHealth, 2000)

The data listing amounts of greywater produced range from 65 l/person/day to 132.5 l/person/day, which is about the double amount.
Another kind of quantification are percentages of total residential sewage, ranging from 50% to 80% in industrialized countries in moderate climate and are <50% for arid climates.

Data for developing countries weren't available. There are different scenarios which influence the quantity of greywater: if there is no tap water (only groundwater well) people will only use about 20 litres per day, though producing max. 15 litres of greywater. If they use dry latrines (no blackwater produced) the greywater is the only real wastewater produced (100%).

3.7 Storage and its consequences

The storage of greywater is very inconsistently discussed; the references may even contradict each other. A summary of the opinions is given in the following chapter. The common point of all opinions is that greywater storage is difficult and the danger of pathogen growth present. The number of thermotolerant coliforms increases strongly during the first days, which could imply that the number of pathogenic microorganisms increases, too.
Another problem poses the depletion of oxygen during the degradation process which can lead to very bad smell.
Most authors agree that it is better to avoid storage, but disinfecting of the greywater could also be a solution to the problem.

Although storage is a key facet of any recycling attempt, little has been reported on the effects of storage on greywater quality. A study conducted at Cranfield University in the UK revealed a rapid decline in organic strength with both real and synthetic greywater under quiescent and agitated conditions. The degradation was shown to follow a first-order decay over an initial 7 day period irrespective of storage conditions, with rate constants between 0.011 per day (quiescent) and 0.622 per day (agitated). Further, the COD: BOD ratio of the water decreased, indicating that the waste was becoming more biodegradable. The concentration of coliforms was shown to increase by 3 log over an initial 5 day period and then remained stable for a further 15 days before numbers started to decrease. However, although there is an increase in indicator species this does not imply an increase in pathogenic microorganisms and hence risk. Thus, a major factor affecting the characteristics of greywater between different recycling schemes is the residence time of the greywater in the collection network, which can range from minutes to days (Jefferson et al., 2001).

(Eriksson et al., 2002) in contrary found that storage for 24 hours improved the quality of the greywater but storage for more than 48 h could be a serious problem as the dissolved oxygen was depleted.

In a third study by (Queensland, 2002), thermotolerant coliforms have been found to multiply by 10 to 100 times during the fist 48 hours of greywater storage before gradually declining. Significant levels of pathogens have been found in stored greywater after eight days. While it is unlikely for pathogens to grow in greywater, the low infective dose of some pathogenic microorganisms are still of concern.

(Marshall, 1996) quotes that storage of greywater should be avoided where possible. Pathogen numbers can increase rapidly in a favourable greywater environment, and stored greywater will begin to smell strongly as it becomes anaerobic.

According to (Christova Boal et al., 1996), the incorporation of collection and storage tanks is undesirable in any greywater design. Tanks containing greywater provide an ideal breeding ground for pathogenic microorganisms and mosquitoes and are a source of odours. Tanks need to be vented and child-proof and comply with local health and plumbing by-laws as well as all tanks must be accessible for cleaning.
Storage of greywater would require the addition of a disinfectant to avoid the biological degradation of fats, soaps, hairs etc. Since the characteristics of greywater depend on the products used in bathrooms, laundry and eventually kitchen, there is no simple solution in selecting appropriate disinfectants. (Christova Boal et al., 1996) demonstrated that some combinations of surface active agents could neutralise certain disinfectants. No specific and generally applicable disinfectant could be identified, thus rendering greywater storage difficult.

3.8 Possible uses

In developed countries, greywater is reused for a whole range of applications:
- Urinal and toilet flushing
- Irrigation of lawns (college campuses, athletic fields, cemeteries, parks and golf courses, domestic gardens)
- Washing of vehicles and windows
- Fire protection
- Boiler feed water
- Concrete production
- Develop and preserve wetlands
- Infiltrate into the ground
- Agriculture and viticulture reuse

The following chapter focuses on the reuse for irrigation (in general sub-surface irrigation) and infiltration since this is what will be mostly done in low-income regions where mainly dry toilets are used and as a consequence no need for flushing exists.

3.9 Environmental and health risks related to greywater reuse

There are a number of problems related to the reuse of untreated greywater. The risk of spreading of diseases, due to the exposure to microorganisms in the water, will be a crucial point if the water is to be reused for e.g. toilet flushing or irrigation. Both inhaling (aerosols) and hand to mouth contact can be dangerous. Growth within the system is another source for microorganisms and some chemicals. (Eriksson et al., 2002)

The greywater that is going to be reused must also be of satisfactory physical quality Suspended solids can cause clogging of the distribution system.

Another problem is the risk of sulphide production, which is produced when oxygen is depleted and gives bad odour.

3.9.1 Infiltration and Irrigation

The major problem related to infiltration of greywater is the risk of contamination of the soil and receiving waters due to the relatively high content of different types of pollutants (chemical compounds and microorganisms). To assess the risk it is necessary to know about the quality of the water to be infiltrated and also about the soil characteristics and processes determining the fate of the pollutants in soil and water.

3.9.1.1 Clogging of soil pores

One possible problem is clogging of the soil pores. Even if the concentrations of solids in the greywater are expected to be lower than in combined wastewater, the combination of colloids and surfactants (from detergents) could cause stabilisation of the colloidal phase, due to sorption of the surfactants on the colloid surfaces. This prevention from agglomeration of the colloidal matter will reduce the efficiency of a pretreatment step including settling of solid matter before infiltration. However, this stabilisation does not mean that the colloids will not induce clogging of the soil matrix (Eriksson et al., 2002).

3.9.1.2 Soil properties

The effects of the infiltration of greywater on soil pH and buffering capacity will be determined by the alkalinity, hardness and pH of the infiltrating water. However, the effect observed will also be influenced by the natural buffering capacity of the soil. The properties of the soil, regarding, for example, sorption capacity of pollutants, will change as a result of the infiltration (Eriksson et al., 2002).

Infiltration and irrigation may lead to elevated concentrations of detergents (for example) in the soil and some plants may suffer due to the alkaline water. When soil pH exceeds 8- 8.5, some micronutrients deficiencies occur.
Phosphorus disposed to clay-soils may make them become phosphate-saturated. There is a potential for leaching to groundwater or runoff to a water course. Excess phosphorous leaching to groundwater in sandy soil might be an even more significant problem (Christova Boal et al., 1996).

3.9.1.3 Microorganisms

Microorganisms represent another problem concerning irrigation with greywater, because of the risk of infection due to direct contact with the water during irrigation, where the application on/in the soil is the most critical moment (Ledin et al., 2001a). According to (Marshall, 1996), greywater should only be applied beneath mulch and soil, because the greywater gets in contact with the topsoil, which is the most active soil horizon, it facilitates destruction of any pathogens, breaks down organic matter and utilises nutrients in greywater. Surface spraying is not recommended, as the potential for human contact is significantly increased. Direct contact is virtually the only way for people to get sick from greywater reuse.

There is also a potential risk of the contamination of soil used for gardening or agriculture or receiving waters used as drinking water supplies.
Microorganisms will be eliminated through numerous interacting reactions including physical, chemical and biological processes. However, physical removing (filtration) is in most cases the dominating process (Ledin et al., 2001a).

3.9.1.4 Fate of pollutants

Evaluating the risk of soil and receiving water pollution due to the infiltration of greywater requires knowledge of the fate of the chemical compounds and microorganisms in soil and water, including the residence times and the transfer factors to adjacent compartments (air, water and sediments). This in turn requires an understanding of the reactions and transport mechanisms to which pollutants are subjected. The main processes determining the fate of pollutants in soils and waters are sorption, volatilisation and degradation. Information about the fate of pollutants is scarce, and about the fate of XOCs very few is known (Ledin et al., 2001a).

3.9.1.5 Mosquito breeding

A major concern with using greywater is the potential health risks associated with ponding of greywater from unsatisfactory disposal practices and inadequately maintained greywater facilities. Surface ponds of greywater and poorly maintained greywater treatment plants provide ideal breeding habitat for mosquitoes.

Some mosquito species are capable to breed in temporary and semi-permanent ponds that develop through poor wastewater disposal practices. Mosquitoes will also breed in any treatment plant, holding tank or receptacle where water is allowed to stagnate for a few days. The potential for mosquito breeding can be minimised by (Queensland, 2002):

- preventing surface ponding and confining greywater within the land application area
- ensuring that tanks which make up the treatment plant and holding tanks are properly sealed against the ingress of mosquitoes

3.9.1.6 Effects of excessive watering

Over application of untreated greywater to a land may result in the development of unsightly areas of grey/green slime. This slime is caused by the presence of soaps, shampoos, detergents and grease in the greywater. Excessive watering with greywater on a small area will cause surface runoff.

The effects of excessive watering can be minimised by (Queensland, 2002):

- having multiple irrigation areas to allow rotation of irrigation
- having adequate irrigation area for the quantity of greywater available and the site and soil conditions.

4 Treatment systems for greywater

4.1 General considerations

Depending above all on the economic aspects and required effluent quality (see below), greywater undergoes different degrees of treatment before being reused or disposed. There are usually three degrees of treatment defined (Morel, 2002).

Primary Treatment
The first step in wastewater treatment is used to remove most materials that float or will settle. Primary treatment removes about 30 percent of the carbonaceous biochemical oxygen demand from domestic sewage.

Secondary Treatment
During the second stage, bacteria consume the organic parts of the waste. Bringing together waste, bacteria, and oxygen accomplish it. This treatment removes floating and settleable solids and about 90 percent of the oxygen-demanding substances and suspended solids. Disinfection is the final stage of secondary treatment.

Tertiary Treatment
The last step consists of an advanced cleaning of wastewater that goes beyond the secondary or biological stage. It is removing nutrients such as phosphorus, nitrogen, and most BOD and suspended solids.

Each treatment stage can be accomplished by a certain system (see table 15). The systems of the different treatment stages can be combined sequentially to obtain the required quality for reuse and disposal.

Table 15: Classification of systems depending on treatment stage

Primary treatment	Secondary treatment	Tertiary treatment
Sedimentation ponds	------------- Constructed wetlands	----------------------
Septic tank	Aerobic ponds	Maturation ponds
Imhoff tank	Baffled septic tank	
	Anaerobic / fixed bed filters	
	Trickling filters	

4.2 Primary treatment systems

4.2.1 Sedimentation ponds

Sedimentation/stabilization ponds shown in figure 1 can be used as first faecal sludge (FS) treatment step when land availability is not a problem. They can receive fresh FS. The raw FS is loaded onto the pond; solids settle and accumulate at the bottom of the pond while the clarified liquid flows out of the pond. Ponds are usually designed with a high retention time. Therefore, not only sedimentation but also anaerobic degradation contributes to the improvement of the effluent quality. It is assumed that large sedimentation ponds are more appropriate for the treatment of fresh public toilet sludge or a FS mixture containing a high amount of public toilet sludge. The reason is that the higher retention time would allow for partial stabilization of the fresh FS and thus reduce the negative impact of intense bubbling on particles settling. Sedimentation ponds have longer sediment removal intervals than septic tanks. Sludge is removed once, twice or more often per year. At least two parallel ponds are required to assure continuous operation. The sediment is removed after removal of the liquid column and a period of drying. Both liquid and sediments require further treatment.

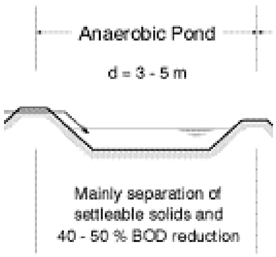


Figure 1: Schematic of a sedimentation pond. Sludge sediments to the bottom of the pond while the clarified liquid flows out of the pond.

Disadvantages High land requirement

Advantages Simple operation
Cheap construction
Good sedimentation properties
Good stabilisation capacities

4.2.2 Septic tank

Septic tanks (Figure 2) are the most common small scale and decentralised treatment plants worldwide. They consist of an underground sedimentation tank having 2 to 3 compartments, in which settled sludge is stabilized by anaerobic digestion. Dissolved and suspended matter leave the tank untreated. They are used for wastewater containing settleable solids, especially domestic wastewater. The settled sludge must be pumped out periodically. In septic tanks, COD is removed to 25 – 50 %.

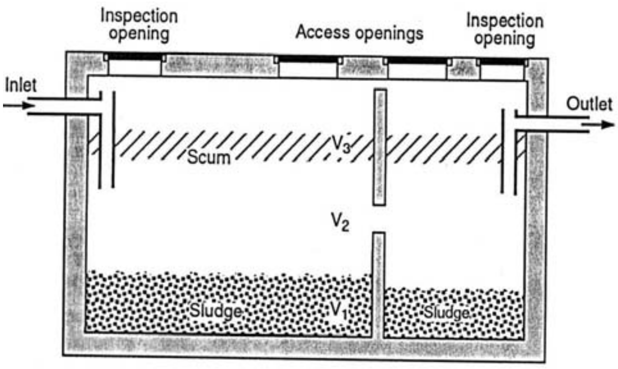


Figure 2: Schematic of a septic tank. Settleable solids in the wastewater sediment to the bottom of the tank. The sludge is anaerobically digested. Dissolved and suspended matter leave the tank.

Disadvantages Low treatment efficiency
Foul-smelling emissions created by anaerobic digestion

Advantages Simple operation
Little space requirements (undergorund)
Cost-efficiency regarding treatment

4.2.3 Imhoff tanks

Imhoff tanks (Figure 3) are used for domestic wastewater with flows above 3 m^3/d. They separate the fresh influent from sludge and consist of a settling chamber being above a digestion chamber. The volume of the settling compartment should be able to contain 50 l/capita and the digestion chamber 120 l/capita. Baffle walls prevent up – flowing foul sludge particles from getting mixed with the effluent. This way, the effluent remains fresh and odourless. COD is removed to 25 – 50 %.

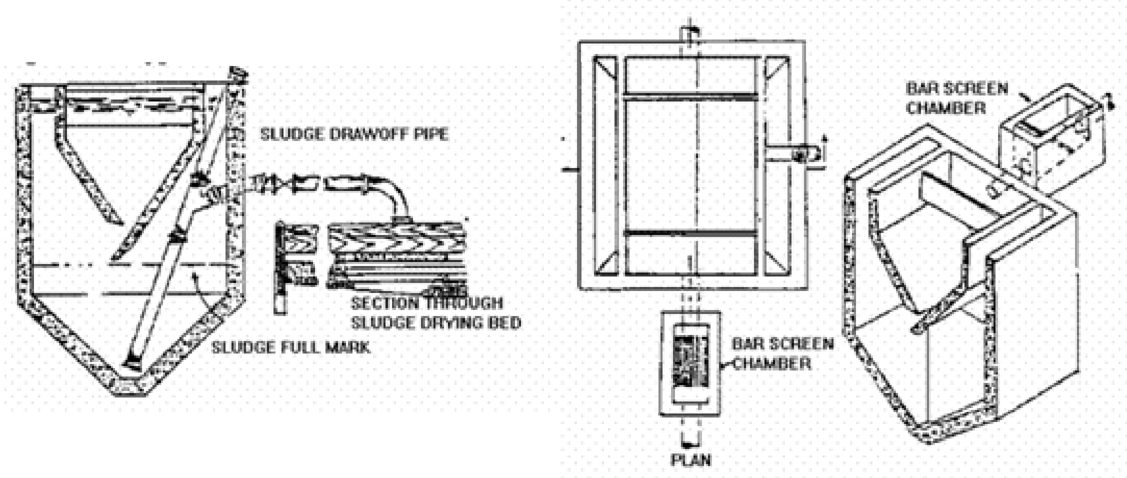


Figure 3: Schematic of an Imhoff tank. The digestion chamber is in the lower part of the tank and the settling chamber in the upper part. The baffle walls are installed diagonally.

Disadvantages More complicated than septic tanks
Low treatment efficiency
Regular de-sludging

Advantages Little space requirements (underground)
Odourless effluent
Clear separation of the two processes sedimentation and fermentation
Durable system

4.3 Secondary treatment systems

4.3.1 Baffled septic tank

These tanks (Figure 4) are an improvement of septic tanks and can treat heavily polluted wastewater like industrial wastewater or all kind of other wastewaters. They consist of 2 to 5 serial chambers with eventually an anaerobic filter in the last part. The first compartment is always a settling chamber followed by a series of up – flow chambers. There is an intensive contact occurring between fresh influent and resident sludge. The process taking place in the chambers is the anaerobic degradation of suspended and dissolved solids. This process leads to a COD removal of 65 – 90 %.

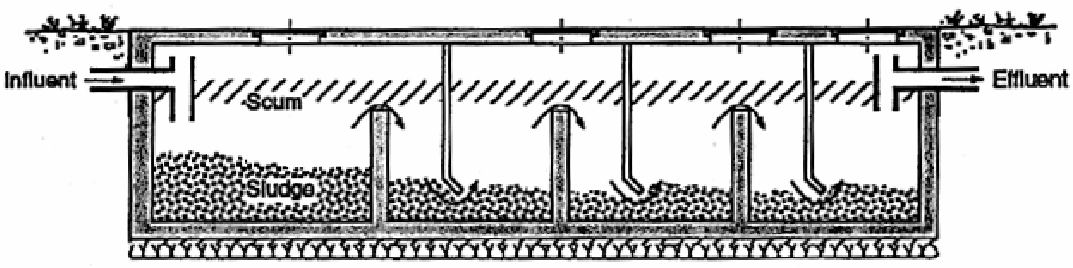


Figure 4: Schematic of a baffled septic tank having 4 chambers. The arrows indicate the flowing direction of wastewater.

Disadvantages	Less efficient with weakly polluted wastewater Long start-up phase
Advantages	High treatment efficiency Simple operation Hardly any blockage Durable system Relatively cheap

4.3.2 Anaerobic / fixed bed filters

Anaerobic filters (Figure 5) can be used for pre-settled domestic and industrial wastewater of narrow COD/BOD ratio. Therefore, they can only be used in combination with primary treatment (for example a septic tank). Anaerobic filters can also treat non – settleable and dissolved solids by bringing them in close contact with active bacteria mass on a filter media. The filter surface should be of 90 to 300 m^2 per m^3 of treated water and be rough. The tank should contain a volume of 0.5 – 1 m^3/capita. The COD removal is about 70 – 90 %.

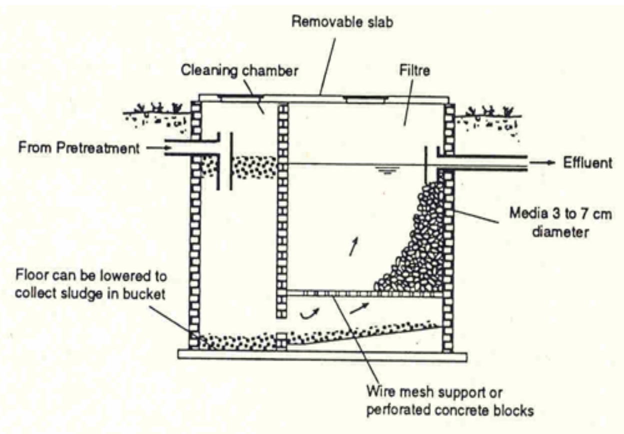


Figure 5: Schematic of an anaerobic tank. Wastewater flows through a cleaning chamber before passing through a filter media.

Disadvantages	High construction costs (filter media) Blockage of filter possible Effluent can smell
Advantages	Simple and durable system if well constructed and properly pre – treated wastewater enters it High treatment efficiency Little space requirements

4.3.3 Trickling filter

A trickling filter (TF) is a wastewater treatment system that biodegrades organic matter and can also be used to achieve nitrification. The wastewater trickles through a circular bed of coarse stones or plastic material. A rotating distributor (a rotating pipe with several holes across it) evenly distributes the wastewater from above the bed. The microorganisms in the wastewater attach themselves to the bed (also known as the filter media), which is covered with bacteria. The bacteria break down the organic waste and remove pollutants from the wastewater.
When excess nutrients become a concern, it becomes necessary to adapt "conventional" sewage treatment systems to meet the increased oxygen demand placed on receiving waters by high ammonia nitrogen concentrations in wastewater effluents. TFs and other attached-growth processes proved to be well – suited for the removal of ammonia nitrogen by oxidizing it to nitrate nitrogen (nitrification).

Disadvantages	Additional treatment may be needed to meet strict discharge standards Regular operator attention needed Relatively high incidence of clogging Relatively low loadings required depending on the media Limited flexibility and control in comparison with activated sludge processes Potential for vector and odour problems
Advantages	Simple, reliable process that is suitable in areas where large tracts of land are not available for a treatment system Effective in treating high concentrations of organic material depending on the type of media used High degree of performance reliability Appropriate for small- to medium-sized communities and onsite systems Ability to handle and recover from shock loads Relatively low power requirements Durability of process elements Level of skill and technical expertise needed to manage and operate the system is moderate

4.4 Secondary and tertiary treatment systems

4.4.1 Constructed wetlands

This system (Figure 6) is used for the treatment of pre – settled domestic or industrial wastewater with COD < 500 mg/l. Wastewater flows horizontally through a filter, which is permanently soaked with water. Plants grow on the filter media in order to assimilate nutrients. Bacteria in the media degrade solids and soluble BOD to inorganic nutrients (ammonia and phosphorous). The granular media filters out solids. The filter works partly aerobic, partly anoxic and anaerobic.
The area needed is approximately 5 m^2/capita. The maximum loading rate for wastewater is 30 l/m^2d and for organic material is 8 g BOD/m^2d. The slope of the impervious liner should be 0.5 – 1 %.

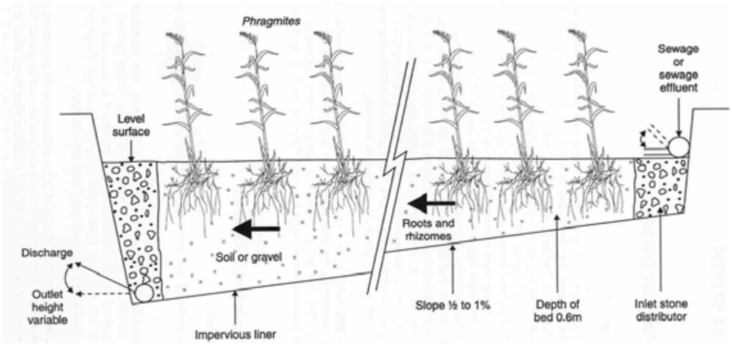


Figure 6: Schematic of a constructed wetland system. Wastewater flows through the soil. Plants growing on the soil assimilate the nutrients of the wastewater and soil bacteria mineralise nutrients.

Disadvantages	High space requirements Costly (gravel) Great care required during construction (pervious liner, etc.) Intensive maintenance during the first 2 years
Advantages	High treatment efficiency, up to 95 % COD removal No wastewater aboveground No nuisance of odour Good nutrient removal

4.4.2 Pond system

This system (Figure 7) consists of a series of artificial ponds comprising an anaerobic pond (see below), two parallel aerobic (facultative) ponds and two serially connected maturation ponds. The total area required amounts 6 to 8 m^2/cap, including land for accession, etc. The net treatment area is 3 – 4 m^2/capita. It is planned for a full treatment of wastewater (primary to tertiary treatment).

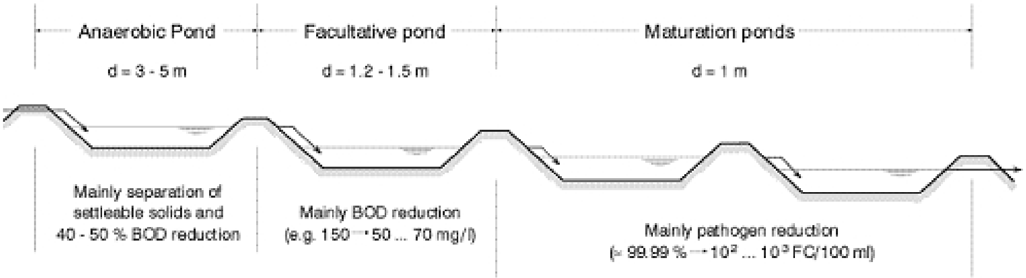


Figure 7: Schematic of a series of ponds.

Disadvantages	Large space requirements Nuisance of mosquitoes and odour if undersized Algae can raise the effluent BOD
Advantages	Simple construction High pathogen removal rate Little maintenance High treatment efficiency and nitrogen removal

4.4.2.1 Anaerobic pond

Its function is the sedimentation and anaerobic digestion of sludge. It works like an open septic tank and can treat highly loaded wastewater (0.1 – 1 kg BOD/m^{3}d) with BOD removal rates of 40 – 60 %. Its minimum depth should be 3 m to guarantee anaerobic conditions. The minimum dimensions of an anaerobic pond are 0.6 m^3/capita and 0.2 m^2/capita. The retention time lasts 1 – 3 days.

4.4.2.2 Aerobic (facultative) pond

Its role is the aerobic degradation of suspended and dissolved matter. The BOD removal rates are 40 – 70 %. The maximum organic load shouldn't go beyond 20 g BOD/m2d. The oxygen supply occurs via water surface and photosynthesis. Its maximum depth should be 1.2 m to guarantee aerobic conditions. The minimum dimensions of an aerobic pond are 1.5 m2/capita for domestic wastewater. The retention time lasts 10 – 20 days.

4.4.2.3 Maturation ponds

Their role is to mediate the final sedimentation of suspended stabilised solids, bacteria mass and pathogens. Their depth amounts 1 m and the area amounts 1.5 m2/capita. The hydraulic retention time lasts approximately 10 days. There are normally 2 – 3 ponds constructed in series.

4.5 Descriptions of systems found in literature

This section presents an overview on different treatment systems found in literature. Six systems combining the treatment options described above will be characterised. These systems were implemented in both developed and developing countries. Different aspects like costs, space requirements, treatment efficiency, strengths and weaknesses will be compared (see table 16) for these systems. Table 17 shows for what habitation size or structure these systems were dimensioned.

Table 16: Comparison of systems in terms of area requirements, costs, strengths and weaknesses

System	Space requirements	Construction costs ($/pers.)	Operation and maintenance costs	Weaknesses	Strengths
Wetparks	40 m^2 / person	375	Medium	High area requirements	Recreational value Biodiversity
Constructed wetlands	0.86 m^2 / person	61	Negligible	None	Low operating costs No need of electricity
Ecomax	100 m^2 / household ≤ 20 m^2 / person	None	High[1]	High area and maintenance requirements High costs	No electricity consumption
Gaia-Movement system	1 m^2 / person for reed bed 2 m^2 / 1000 l water used for duck weed pond	None	Low	Performance of system probably strongly depending on external factors	Construction easily done on one's own
Rota-Loo Greywater System – Niimi Absorption Trench	See figure for Niimi Absorption Trench	None	Very little on-going mainte-nance Desludging of the tank every 3 years	Quite high area requirements No water let for reuse	Recreational value Probably low operating costs
Rota-Loo Greywater System – Reed Bed	See figure for Reed Bed	None	Harvesting of 1/3 of the reeds every year Watering of the reeds if house unoccupied	Quite high area requirements No water let for reuse	Recreational value Probably low operating costs

[1] Quarterly septic tank pump-out costs 250 $

Table 17: Dimensioning of different systems

	Single household	Neighbourhood	Hole community
Wetpark		X	X
Constructed wetland	X	X	X
Ecomax	X	X	
Gaia-movement system	X		
Rota-Loo greywater system	X	X	

4.5.1 Wetpark

The name *wetpark* was given by the author (Günther, 2000) to this purification system because of its park-like composition and its wetland type structure (see Figure 8). Wetparks are plants that encourage the subsurface flow of water and enhance interactions of the vegetation and microorganisms occurring in a riparian ecotone. They consist of four different elements, which are a. a section filled with lime-gravel, b. shore zones, c. ponds and d. a sand filter.

Before entering the pond system, water is distributed over a bed filled with lime-gravel by means of inlet pipes. Lime-gravel increases the surface for organic material reduction by aerobic bacteria. After water has passed through the gravel bed, it is let in the root-zone of the planted vegetation of the shore. Finally, it is stored in a pond. Purification in the shore-pond system is repeated three times consecutively. After the last pond, water is let into a sand filter and is collected in a well.

In order to prevent water from percolating in deeper soil layers, a waterproof layer is placed under the whole purification plant.

The vegetation chosen is that prevailing in the normal wetland communities in the region. In Switzerland for example, you would choose *Phragmites australis* and *Typha latifolia*. The plants are continuously harvested and composted, in order to remove nutrients from the system.
Some fishes and crayfishes are introduced into the ponds to control insect larvae and digest leaf litter and other organic matter.

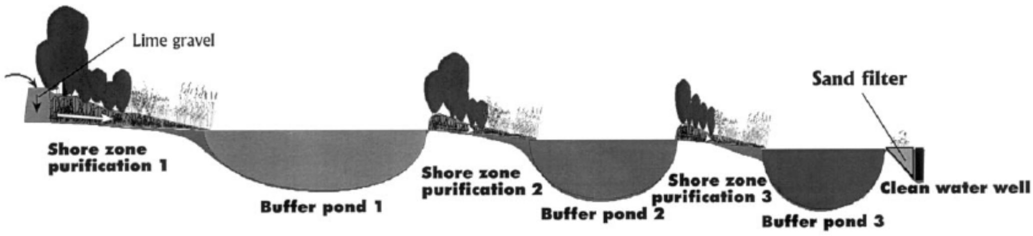


Figure 8: Outline of the triplicate shore – pond system

4.5.2 Constructed wetlands

Here the example of a system constructed for the household level is given. Nevertheless, the authors (Shrestha et al., 2001) have described systems for other levels that are constructed and dimensioned differently.
Greywater is collected in a two-chambered settling tank (500 l) for pretreatment. The pretreated water is led into a tank (200 l), which feeds a vertical flow bed (6 m^2). The flow bed is filled with coarse sand and planted with common reed (*Phragmites karka*) and *Canna sp*.. The treated water is collected in an underground tank.
The system doesn't need any electrical devices. Water is flushed hydro-mechanically into the bed 3 to 4 times a day. The collected water can be reused for flushing, gardening and cleaning.

4.5.3 Ecomax

The author (Bowman, 1996) defines six functional elements for the Ecomax septic system (Figure 9):

- Two sequential septic tanks
- Two Ecomax cells, used in rotation, each comprising a storage and leaching vessel
- Amended soil treatment medium
- A perimeter sub-surface drain to collect treated water for reuse
- Sand veneer to provide substrate for grass growth and as means of blending the cells to their landscape setting
- Grass cover

Wastewater is led into septic tanks, where sedimentation, floatation and aerobic digestion occur. After 2-3 days residence, the pre-treated effluent flows out of the tank and into the infiltration structure located in the Ecomax cells. Effluent inside the infiltration structure flows radially into the soil and towards the perimeter bund where it exits the system.

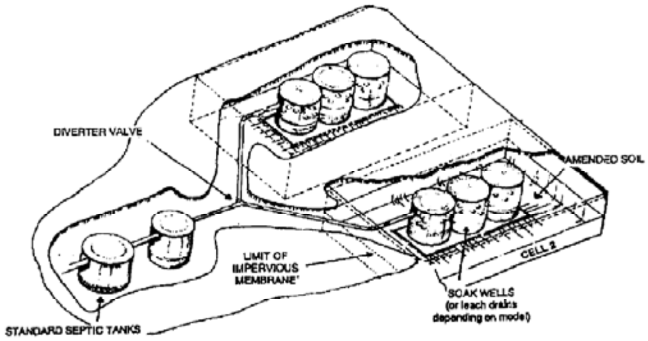


Figure 9: Ecomax septic system. The septic tanks are linked to two Ecomax cells. The effluent of the cells flows radially into the soil and towards the perimeter bund.

4.5.4 Gaia-Movement system

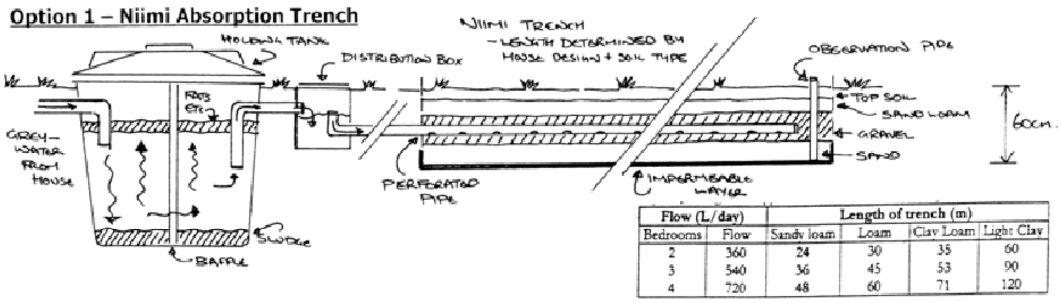
The Gaia-Movement system consists of a drum filled with sand and a duckweed pond or a reed bed.
Wastewater is piped to the sand-filled drum. At the end of the pipe, a mosquito net catches possible waste. Then the water is let through the drum filled with sand. At the bottom of the drum, a net stops sand coming into the outlet. After being filtered in the sand, greywater is piped into the duckweed pond or the reed bed, where it is treated. At the end of the whole process, the treated water is collected in a container and can be used for gardening.
There are many tasks the owner of this system has to do to maintain it. The mosquito net, which catches waste, has to be emptied. Some of the duckweeds have to be removed every day. The reed should be cut once or twice a year. When the sand filter fills up with waste, the sand should be changed.

4.5.5 Rota-Loo greywater system

There are two different options of systems (see Figure 10 and Figure 11) described by the company (Environment Equipment, www.rotaloo.com):

4.5.5.1 Niimi absorption trench

Greywater from the building is piped into a 2500 l *holding tank*. The holding tank is used as a surge tank and to catch any material that may have been washed down the sink. Material falls to the bottom and fats float on the top. The clearer water from the middle of the tank flows into a *distribution box*. The distribution box is used to determine which trench is being used and which one(s) are being rested. Every trench should be swapped over every six months.
The holding tank should be desludged at least once every three years.
The principle of the Niimi absorption trench is to keep the wastewater in an aerobic state near the surface of the soil where microorganisms and other soil fauna digest nutrients and pollutants.

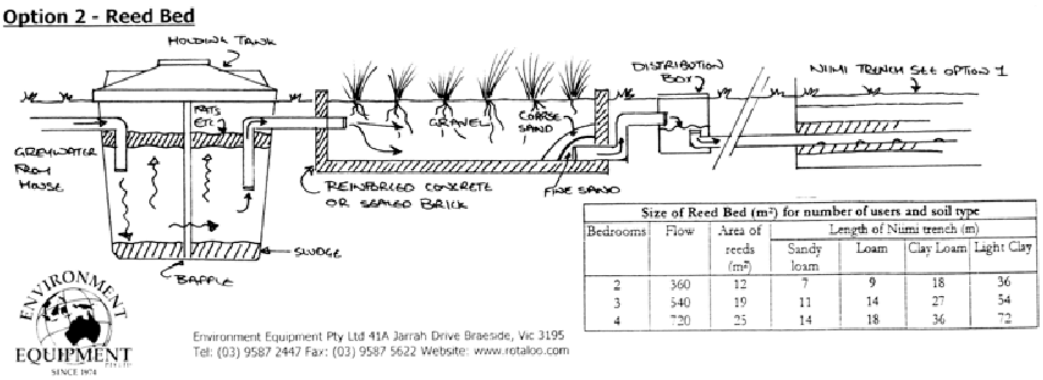


Flow (L/day)		Length of trench (m)			
Bedrooms	Flow	Sandy loam	Loam	Clay Loam	Light Clay
2	360	24	30	35	60
3	540	36	45	53	90
4	720	48	60	71	120

Figure 10: Schematic of a Niimi absorption trench. The holding tank and the distribution box are also illustrated (on the left side).

4.5.5.2 Reed bed filter system coupled with Niimi absorption trench

In this option, a supplementary element is added between the holding tank and the distribution box. The element in question is a reed bed with a slight slope.
The reed bed uses the principles of evaporation and transpiration to process the greywater.



Size of Reed Bed (m²) for number of users and soil type						
Bedrooms	Flow	Area of reeds (m²)	Length of Niimi trench (m)			
			Sandy loam	Loam	Clay Loam	Light Clay
2	360	12	7	9	18	36
3	540	19	11	14	27	54
4	720	25	14	18	36	72

Figure 11: Schematic of a Reed bed filter. The reed bed is installed between the holding tank and the distribution box.

4.6 Possible reuse options

Many different reuse options exist for treated greywater:

- Residential reuse (flushing toilets, hand washing, cleaning, gardening, ...)
- Irrigation of agricultural areas
- Industry (washdown, cooling water, makeup water, ...)
- Discharge into nearby streams, lakes or other water body
- ...

The level of treatment necessary depends on how the greywater is to be reused. Greywater reused for toilet flushing or for surface irrigation will need to be well filtered and disinfected, and in some instances, dyed to prevent confusion with potable water. Greywater used for subsurface irrigation may require only coarse filtration because the risk of human and vector contact is reduced (Finch et al., 2003). If one plans to install a greywater treatment system, one does best contacting local authorities to learn more about current legislation.
For further information about required effluent quality, the chapter about guidelines can be checked.

5 Water recycling standards, Guidelines

There is very few information available about guidelines for greywater reuse, mostly because so far hardly any guidelines for greywater reuse exist. The WHO is currently revising the last edition of their guidelines for reclaimed water reuse (see detailed description below), and will in future include guidelines for greywater reuse.

The guidelines for reclaimed water reuse could be applied to greywater, too, as long as no greywater guidelines exist. Because greywater doesn't include faeces and therefore is less polluted, the parameters set in the reclaimed water guidelines (for example faecal coliforms, BOD and others) can be easier met by greywater than by reclaimed water. The parameters used in the reclaimed water guidelines should guarantee the safety of human health and environment, and as long as at least those guidelines are met by greywater, no serious hazards are to be expected.

The most “famous” and most often referred to guidelines about wastewater reuse are those of the WHO “Guidelines for the safe use of wastewater and excreta in agriculture and aquaculture” (WHO, 1989b) and those of the US EPA (U.S. Environmental Protection Agency) “Guidelines for water reuse” (USEPA, 2004). The more recently developed USEPA guidelines are based on the Californian model and the accumulated experience of other states (Gregory et al., 1996). But with the exception of Arizona and New Mexico, in most states, the requirements for the handling of greywater differ little from those for blackwater. Compiled data about the regulations in the states of the US are found in (TOWTRC, 2003).

5.1 General remarks on guidelines

The acceptability of recycled water for any particular end use is dependent on its physical, chemical and microbiological quality.
There is some commonality in the water quality determinants used to define bacteriological quality, biodegradability, clarity and acidity; though the actual absolute permitted levels vary considerably.

Two groups of standards can be identified from two different ideologies. The first of these is based on the quality of the greywater being commensurate with its application, and in such cases the standards are similar to those of bathing water since the level of risk to the user is about the same. In these more pragmatic approaches the main water quality criteria relates to coliform concentration. This approach is used by the WHO guidelines.

The alternative approach is more conservative and considers greywater treatment in a similar manner to that of municipal or industrial effluent. In these cases standards include terms for BOD_5, turbidity as well as more restrictive levels of coliforms. In countries such as the US and Japan where greywater recycling has been practised for some time, the more conservative approach is taken (Jefferson et al., 2001).

Public health protection is a key consideration, and thus all water recycling standards include parameters relating to the potential for disease transmission. Indicator organisms are generally preferred due to their ease of measurement and familiarity with their use in the water industry (Jefferson et al., 2001).

Standards or guidelines for wastewater quality for crop irrigation generally specify both explicit standards (for example maximum coliform concentrations) and minimum treatment requirements (primary, secondary and tertiary) according to the class of crop to be irrigated (consumable, non-consumable), one example for this approach are the US EPA guidelines (WHO, 1989b)

The WHO standards can be achieved by cheaper, simpler technologies than the US EPA guidelines. The US EPA approach has been to specify both treatment processes and water quality parameters for a particular application. The arguments for such an approach are that (Gregory et al., 1996):

- surrogate parameters may not adequately characterize reclaimed water quality;
- specifying treatment trains and surrogate parameters removes the need to monitor for large numbers of chemicals or pathogenic microorganisms;
- the need to monitor specific pathogens such as viruses is eliminated reducing costs and time;
- treatment reliability is enhanced

Virus limits are not recommended as (Gregory et al., 1996):

- there is evidence demonstrating viral removal following filtration and disinfection;
- virus monitoring is slow, expensive and imprecise;
- 28 days are needed for virus identification;
- there is no consensus on the health significance of low levels of viruses in reclaimed wastewater

5.1.1 Conceptual analysis or ranges of risk

The incidence of disease is dependent upon more than just the concentration of organisms. It is therefore difficult to protect public health only by editing guidelines based on concentrations of coliforms. Additional components (variations in population size, dose-response, exposure and time elapsed between generation and application of greywater) should be considered and drew together to enable an analysis of risks ran by different reuse options. Table 18 shows estimates of the maximum and minimum bounds associated with variations in the population, human exposure, dose-response and time elapsed between generation and application. A scale of lower, intermediate and higher risk from greywater reuse was subjectively applied to each factor by (Dixon et al., 1999).

Table 18: Conceptual analysis of range of risks from greywater re-use (Dixon et al., 1999)

	Lower risk	Intermediate risk	Higher risk
Population	Small population (single family)	-	Large population (multi-occupancy)
Exposure	No body contact (Sub-surface irrigation)	Some contact (WC flushing, bathing)	Ingestion (drinking)
Dose-Response	< 1 Virus per sample < 1 Bacteria per sample	-	> 1 Virus per sample > 10^6 Bacteria per sample
Delay before reuse	Immediate reuse	Reused within hours	Reused within days

5.2 WHO Guidelines for agricultural use of wastewater

Standards developed 10-20 years ago (1969-1979!) tended to be very strict, as they were based on an evaluation of potential health risks associated with pathogen survival in wastewater, in soil and on crops, and on technical feasibility. The technology of choice for pathogen removal at that time was effluent chlorination.

Evaluation of the credible epidemiological evidence – that was, an appraisal of the actual, as opposed to potential, health risks – indicated that these standards were unjustifiably restrictive. As a result of those considerations, a meeting of experts held in Engelberg, Switzerland, in July 1985, recommended the guidelines shown in table 19 (WHO, 1989b).

Table 19: Tentative microbiological quality guidelines for treated wastewater reuse in agricultural irrigation (WHO, 1989b)

Reuse process	Intestinal nematodes (arithmetic mean no. of viable eggs per litre)	Faecal coliforms (geometric mean no. per 100 ml)
Restricted use: irrigation of trees, fodder crops, industrial crops, fruit trees and pasture	≤ 1	Not applicable
Unrestricted use: irrigation of edible crops, sport fields and public parks	≤ 1	≤ 1000

The irrational application of unjustifiably strict microbial standards (as mentioned above) for wastewater irrigation had led to an anomalous situation. Standards were often not enforced at all and serious public health problems resulted from totally unregulated illegal irrigation of salad crops with raw wastewater as it is in fact widely practised in many developing countries. The WHO approach called for realistic revised standards which were stricter for helminths removal but more feasible regarding bacterial levels (WHO, 1989b).

For developing countries, it is therefore more feasible to rely on the WHO guidelines for their own legislation than on the following USEPA guidelines.

5.3 US EPA Guidelines for agricultural and recreational use of wastewater

There are no federal regulations governing water reuse in the US. The regulatory burden rests with the individual states. This has resulted in differing standards among states that have developed criteria. In 1992, the US EPA published guidelines that are intended to provide guidance to states that have not developed their own criteria or guidelines (Crook and Surampalli, 1996). An overview of regulations of almost all states is given in the literature research of Finch et al. (TOWTRC, 2003).

(USEPA, 2004) gives an overview over the threshold values used in several states for different applications for reclaimed water.
In the following, the data for agricultural and recreational reuse are showed, whereas data for urban and industrial reuses as well as use for groundwater recharge and augmentation of potable supplies can be found in (USEPA, 2004).

5.3.1 Irrigation of food crops

The use of reclaimed water for irrigation of food crops is prohibited in some states, while others allow irrigation of food crops with reclaimed water only if the crop is to be processed and is not to be eaten raw.

Table 20: Agricultural Reuse - Food Crops (USEPA, 2004)

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	Secondary treatment, filtration, and disinfection	Oxidized, coagulated, filtered, and disinfected	Secondary treatment, filtration, and high-level disinfection	Oxidized, filtered, and disinfected	Secondary treatment and disinfection	NS (1)	Oxidized, coagulated, filtered, and disinfected
BOD5	NS	NS	20 mg/l $CBOD_5$	NS	30 mg/l	5 mg/l	30 mg/l
TSS	NS	NS	5 mg/l	NS	NS	NS	30 mg/l
Turbidity	2 NTU (Avg)	2 NTU (Avg)	NS	2 NTU (Max)	NS	3 NTU	2 NTU (Avg)
	5 NTU (Max)	5 NTU (Max)					5 NTU (Max)
Coliform	Fecal	Total	Fecal	Fecal	Fecal	Fecal	Total
	None detectable (Avg)	2.2/100 ml (Avg)	75% of samples below detection	2.2/100 ml (Avg)	200/100 ml (Avg)	20/100 ml (Avg)	2.2/100 ml (Avg)
	23/100 ml (Max)	23/100 ml (Max in 30 days)	25/100 ml (Max)	23/100 ml (Max in 30 days)	400/100 ml (Max)	75/100 ml (Max)	23/100 ml (Max)

(1) NS - Not specified by state regulations

5.3.2 Irrigation of non-food crops

The use of reclaimed water for agricultural irrigation of non-food crops presents a reduced opportunity of human exposure to the water, resulting in less stringent treatment and water quality requirements than other forms of reuse.

Table 21: Agricultural Reuse - Non-Food Crops (USEPA, 2004)

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	Secondary treatment and disinfection	Secondary-23, Oxidized, and disinfected	Secondary treatment, basic disinfection	Oxidized, filtered, and disinfected	Secondary treatment and disinfection	NS (1)	Oxidized and disinfected
BOD_5	NS	NS	20 mg/l $CBOD_5$	NS	30 mg/l	5 mg/l	30 mg/l
TSS	NS	NS	20 mg/l	NS	NS	NS	30 mg/l
Turbidity	NS	NS	NS	2 NTU (Max)	NS	3 NTU	2 NTU (Avg)
							5 NTU (Max)
Coliform	Fecal	Total	Fecal	Fecal	Fecal	Fecal	Total
	200/100 ml (Avg)	23/100 ml (Avg)	200/100 ml (Avg)	2.2/100 ml (Avg)	200/100 ml (Avg)	20/100 ml (Avg)	23/100 ml (Avg)
	800/100 ml (Max)	240/100 ml (Max in 30 days)	800/100 ml (Max)	23/100 ml (Max)	400/100 ml (Max)	75/100 ml (Max)	240/100 ml (Max)

(1) NS - Not specified by state regulations

5.3.3 Unrestricted recreational reuse

As with unrestricted urban reuse, unrestricted recreational reuse involves the use of reclaimed water where public exposure is likely, thereby necessitating a high degree of treatment.

Table 22: Unrestricted Recreational Reuse (USEPA, 2004)

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	NR [1]	Oxidized, coagulated, clarified, filtered, and disinfected	NR	NR	Secondary treatment and disinfection	NS	Oxidized, coagulated, filtered, and disinfected
BOD_5	NR	NS [2]	NR	NR	30 mg/l	5 mg/l	30 mg/l
TSS	NR	NS	NR	NR	NS	NS	30 mg/l
Turbidity	NR	2 NTU (Avg) 5 NTU (Max)	NR	NR	NS	3 NTU	2 NTU (Avg) 5 NTU (Max)
Coliform	NR	Total 2.2/100 ml (Avg) 23/100 ml (Max in 30 days)	NR	NR	Fecal 2.2/100 ml (Avg) 23/100 ml (Max)	Fecal 20/100 ml (Avg) 75/100 ml (Max)	Fecal 2.2/100 ml (Avg) 23/100 ml (Max)

(1) NR - Not regulated by the state
(2) NS - Not specified by state regulations

5.3.4 Restricted recreational reuse

State regulations and guidelines regarding treatment and water quality requirements for restricted recreational reuse are generally less stringent than for unrestricted recreational reuse since the public exposure to the reclaimed water is less likely.

Table 23: Restricted Recreational Reuse (USEPA, 2004)

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	Secondary treatment, filtration, and disinfection	Secondary-23, oxidized, and disinfected	NR [1]	Oxidized, filtered, and disinfected	Secondary treatment and disinfection	NS	Oxidized and disinfected
BOD_5	NS [2]	NS	NR	NS	30 mg/l	20 mg/l	30 mg/l
TSS	NS	NS	NR	NS	NS	NS	30 mg/l
Turbidity	2 NTU (Avg) 5 NTU (Max)	NS	NR	2 NTU (Max)	NS	NS	2 NTU (Avg) 5 NTU (Max)
Coliform	Fecal None detectable (Avg) 23/100 ml (Max)	Total 2.2/100 ml (Avg) 23/100 ml (Max in 30 days)	NR	Fecal 2.2/100 ml (Avg) 23/100 ml (Max)	Fecal 200/100 ml (Avg) 23/100 ml (Max)	Fecal 200/100 ml (Avg) 800/100 ml (Max)	Total 2.2/100 ml (Avg) 23/100 ml (Max)

(1) NR - Not regulated by the state
(2) NS - Not specified by state regulations

5.3.5 Short-term use – long-term use

The recommended maximum concentrations for “long-term continuous use on all soils” are set conservatively to include sandy soils that have low capacity to leach (and so to sequester or remove) the element in question. These maxima are below the concentrations that produce toxicity when the most sensitive plants are grown in nutrient solutions or sand cultures to which the pollutant has been added. Phytotoxicity will not inevitably occur when the suggested limit is exceeded. Most of the elements are readily fixed or tied up in soil and accumulate with time. Repeated applications in excess of suggested levels might induce phytotoxicity. The criteria for short-term use (up to 20 years) are recommended for fine-textured neutral and alkaline soils with high capacities to remove the different pollutant elements.

Table 24: Recommended Limits for Constituents in Reclaimed Water for Irrigation (USEPA, 2004)

Constituent	Long-Term Use (mg/l)	Short-Term Use (mg/l)	Remarks
Aluminum	5.0	20	Can cause nonproductiveness in acid soils, but soils at pH 5.5 to 8.0 will precipitate the ion and eliminate toxicity.
Arsenic	0.10	2.0	Toxicity to plants varies widely, ranging from 12 mg/L for Sudan grass to less than 0.05 mg/L for rice.
Beryllium	0.10	0.5	Toxicity to plants varies widely, ranging from 5 mg/L for kale to 0.5 mg/L for bush beans.
Boron	0.75	2.0	Essential to plant growth, with optimum yields for many obtained at a few-tenths mg/L in nutrient solutions. Toxic to many sensitive plants (e.g., citrus) at 1 mg/L. Usually sufficient quantities in reclaimed water to correct soil deficiencies. Most grasses are relatively tolerant at 2.0 to 10 mg/L.
Cadmium	0.01	0.05	Toxic to beans, beets, and turnips at concentrations as low as 0.1 mg/L in nutrient solution. Conservative limits recommended.
Chromium	0.1	1.0	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on toxicity to plants.
Cobalt	0.05	5.0	Toxic to tomato plants at 0.1 mg/L in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Copper	0.2	5.0	Toxic to a number of plants at 0.1 to 1.0 mg/L in nutrient solution.
Fluoride	1.0	15.0	Inactivated by neutral and alkaline soils.
Iron	5.0	20.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of essential phosphorus and molybdenum.
Lead	5.0	10.0	Can inhibit plant cell growth at very high concentrations.
Lithium	2.5	2.5	Tolerated by most crops at concentrations up to 5 mg/L; mobile in soil. Toxic to citrus at low doses - recommended limit is 0.075 mg/L.
Manganese	0.2	10.0	Toxic to a number of crops at a few-tenths to a few mg/L in acidic soils.
Molybdenum	0.01	0.05	Nontoxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high levels of available molybdenum.
Nickel	0.2	2.0	Toxic to a number of plants at 0.5 to 1.0 mg/L; reduced toxicity at neutral or alkaline pH.
Selenium	0.02	0.02	Toxic to plants at low concentrations and to livestock if forage is grown in soils with low levels of selenium.
Tin, Tungsten, & Titanium	-	-	Effectively excluded by plants; specific tolerance levels unknown
Vanadium	0.1	1.0	Toxic to many plants at relatively low concentrations.
Zinc	2.0	10.0	Toxic to many plants at widely varying concentrations; reduced toxicity at increased pH (6 or above) and in fine-textured or organic soils.
Constituent	**Recommended Limit**		**Remarks**
pH	6.0		Most effects of pH on plant growth are indirect (e.g., pH effects on heavy metals' toxicity described above).
TDS	500 - 2,000 mg/l		Below 500 mg/L, no detrimental effects are usually noticed. Between 500 and 1,000 mg/L, TDS in irrigation water can affect sensitive plants. At 1,000 to 2,000 mg/L, TDS levels can affect many crops and careful management practices should be followed. Above 2,000 mg/L, water can be used regularly only for tolerant plants on permeable soils.
Free Chlorine Residual	<1 mg/l		Concentrations greater than 5 mg/l causes severe damage to most plants. Some sensitive plants may be damaged at levels as low as 0.05 mg/l.

5.4 Compilation of other guidelines

5.4.1 Developing countries

Some examples for guidelines in developing countries were found in (WHO, 1989b), but they refer to reclaimed water and not to greywater. The information is shown in table 25.

Table 25: Examples of microbiological standards for wastewater used for crop irrigation (WHO, 1989b)

Country	Restricted irrigation	Unrestricted irrigation
Values found in greywater, depending on source (see table 11)	Thermotolerant coliforms: 0.2 x 10^6 – 3.75 x 10^8/ 100ml Total coliforms: 56 – 2.8 x 10^7/ 100 ml Faecal coliforms: 1 – 8 x 10^6/ 100 ml	
Oman	Maximum 23 TC/100ml Average <2.2 TC/100ml Greenbelt irrigation only	Crop irrigation not permitted
Kuwait	<10'000 TC/100ml	<100 TC/100ml Not salad crops or strawberries
Saudi Arabia	Use of secondary effluent permitted for forage crops, field crops and vegetables which are processed and also for landscape irrigation	<2.2 TC/100ml <50 FC/100ml
Tunisia	Fruit trees, forage crops and vegetables eaten cooked: - secondary treatment (including chlorination) - absence of *Vibrio cholerae* and salmonellae	No irrigation of vegetables eaten raw
Mexico	For recreational areas: <10'000 TC/100ml <2'000 FC/100ml	For vegetables eaten raw and fruits with possible soil contact: <1'000 TC/100ml
Peru	Treatment specified depending on reuse option	No irrigation of low-growing and root crops that may be eaten raw

TC= total coliforms; FC= faecal coliforms

The comparison with the coliform levels found in greywater shows that treatment of greywater is necessary to meet the threshold levels given for several countries in table 25, even more so for unrestricted reuse.

5.4.2 Developed countries

The following table 26 shows the microbiological boundary values for treated wastewater aimed at a non-potable reuse in industrial countries.

Table 26: Microbiological guidelines for reuse of treated wastewater for non-potable use

Country, Institution	Boundary value	Type	Reuse option	Reference
Values found in greywater, depending on source (see table 11)	Thermotolerant coliforms: 0.2 x 10^6 – 3.75 x 10^8/ 100ml Total coliforms: 56 – 2.8 x 10^7/ 100 ml Faecal coliforms: 1 – 8 x 10^6/ 100 ml			(See table 11)
California, USA	2.2 total coliforms/ 100 ml	Treated wastewater for non-potable use	Toilet and urinal flushing, commercial laundries, decorative fountains	(Crook and Surampalli, 1996)
Florida USA	0 detected coliforms/ 100 ml	Treated wastewater for non-potable use	Toilet flushing, irrigation of recreation areas	(Crook and Surampalli, 1996)
Australia	< 10'000 thermotolerant coliforms/ 100 ml	Treated wastewater for non-potable use	Non-human food chain application	(Gregory et al., 1996)
Australia	< 1000 thermotolerant coliforms/ 100 ml	Treated wastewater for non-potable use	Lower contact applications	(Gregory et al., 1996)
Australia	< 150 thermotolerant coliforms/ 100 ml		Medium contact (recreational) applications	(Gregory et al., 1996)
Australia	< 10 thermotolerant coliforms/ 100 ml	Treated wastewater for non-potable use	Higher contact applications such as irrigation of salad vegetables	(Gregory et al., 1996)
Germany	<100 total coliforms / 100 ml < 10 feacal coliforms / 100 ml < 1 Pseudomonas aeruginosa / 100 ml	Treated wastewater for non-potable use		(Nolde, 1999) and references therein

The same conclusion can be drawn as in the comparison above, greywater treatment is necessary to meet the guidelines concerning coliform levels.

In Australia, direct greywater reuse for garden irrigation is currently illegal in all states, but greywater which has passed through a secondary treatment system (e.g. reedbed or aerating package plant) may be reused for irrigation in certain states if disinfection is provided (e.g. chlorine tablets, UV or ozone).
Regulations are set by conservative state health departments whose main concern is the perceived public health risk associated with greywater reuse. Encouragingly, direct greywater reuse for garden irrigation is now being examined by some Australian water authorities as an option for reducing fresh water demands in rural and urban areas (Marshall, 1996).

Some (industrial) countries have guidelines for the use of reclaimed water that include more than just microbiological threshold values, but also establish quality criteria for physical and chemical parameters. A compilation of such guidelines is given in table 27.

Table 27: Summary of water quality standards and criteria suitable for domestic water recycling (Jefferson et al., 2001)

	Total coliforms count/ 100 ml	**Faecal Coliforms**	**BOD_5 (mg/l)**	**Turbidity (NTU)**	**Cl_2 (mg/l)**	**pH**
Values found in greywater, depending on source (See table 11)	56 – 2.8×10^7	1 – 8×10^6	48 - 380	14 - 370	3.1 - 88	5 - 10
Bathing water standards*	10'000 (m), 500 (g)	2'000 (m); 100 (g)				6- 9
USA, NSF		< 240	45	90		
Australia	<1	<4	20	2		
UK (BSIRA)	Non detectable					
Japan	<10	<10	10	5		6- 9
Germany (g)	100	500	20	1-2		6- 9

*** = bathing water standards suggested as appropriate for domestic water recycling; Council of the European Communities, 1976; (g) = guideline; (m) = mandatory; BSIRA: Building Services Information and Research Association**

The greywater does necessarily need treatment because of the BOD levels found in it, as in most cases because of turbidity levels, too. The pH level of greywater in contrary shouldn't pose a problem to meet the threshold levels given in table 27.

5.4.3 FAO guidelines

Table 28 shows the guidelines for the quality of water used for irrigation proposed by the FAO. This values don't refer to reclaimed or greywater, but are mentioned here because they safeguard the health of crops and soils and so should also be met by greywater and reclaimed water used for irrigation.

Table 28: Guidelines for interpretation of water quality for irrigation (FAO, 1994 (adapted from FAO,1985)) Cursive and in brackets the corresponding values for greywater are given.

Potential irrigation problem	Units	Degree of restriction on use		
		None	Slight to moderate	Severe
Salinity				
Ec_w[1]	dS/m	< 0.7	0.7 - 3.0	> 3.0
or				
TDS *(126- 175)*	mg/l	< 450	450 - 2000	> 2000
Infiltration				
SAR[2] = 0 - 3 and EC_w		> 0.7	0.7 - 0.2	< 0.2
3 -6		> 1.2	1.2 - 0.3	< 0.3
6-12		> 1.9	1.9 - 0.5	< 0.5
12-20		> 2.9	2.9 - 1.3	< 1.3
20-40		> 5.0	5.0 - 2.9	< 2.9
Specific ion toxicity				
Sodium (Na) *(7.4- 480)*				
Surface irrigation	SAR	< 3	3 - 9	> 9
Sprinkler irrigation	me/l	< 3	> 3	
Chloride (Cl) *(3.1- 88)*				
Surface irrigation	me/l	< 4	4 - 10	> 10
Sprinkler irrigation	m^3/l	< 3	> 3	
Boron (B) *(<0.1- 0.5)*	mg/l	< 0.7	0.7 - 3.0	> 3.0
Miscellaneous effects				
Nitrogen (NO_3-N)[3] *(0.4- 4.9)*	mg/l	< 5	5 - 30	> 30
Bicarbonate (HCO_3)	me/l	< 1.5	1.5 - 8.5	> 8.5
pH *(5- 10)*	Normal range 6.5-8			

1 ECw means electrical conductivity in deciSiemens per metre at 25°C; 2 SAR means sodium adsorption ratio; 3 NO3-N means nitrate nitrogen reported in terms of elemental nitrogen

The comparison between those values found in greywater and the FAO guidelines shows that:

- TDS, Boron and Nitrogen values are lower than the guideline values, causing no problems;
- Sodium, Chlorine and pH values can interfere with the guidelines, making treatment necessary.

6 Planning of a treatment system

Before installing a certain treatment system, many different elements must be considered to make the right choice. Here the most important elements are mentioned (Morel, 2002):

- Costs
- Physical and geographical environment
- Local availability of manpower and material
- Social and socio-economic circumstances
- Legal framework
- Characteristics and quantities of greywater, fluctuations (see required data listed below)
- Way effluent (treated greywater) is disposed or reused

6.1 Greywater data

The following data are required to know the characteristics and quantities of greywater in order to choose the correct system (Morel, 2002):

- Daily greywater flow
- Hours of major greywater flow or other data describing fluctuation (peak flow)
- Average COD values and range of fluctuation
- Average BOD values or average COD/BOD ratio
- Suspended solids content, percentage of settleable solids
- pH
- Ambient temperature and temperature of greywater source

6.2 Economical considerations

Economic calculation depends on several parameters, which in turn depend on the local settings (Morel, 2002):

1. Investment costs
    - Costs of land
    - Construction costs, also taking into account the lifetime of the hardware
    - Planning costs, including transport to the site and laboratory costs for initial greywater analysis
2. Running costs, including costs of personnel for operation, maintenance and management, costs for de – sludging
3. Rate of interest
4. Potential income from by – products, e.g. biogas, irrigation water, etc. This parameter is very difficult to quantify

A general rule for the choice of a system regarding to financial aspects is to first think of ponds, then tanks and at last filters.

6.3 Socio-cultural and gender aspects

Socio-cultural and gender aspects were often neglected in past sanitation projects. But the success of the implementation of a new treatment plant strongly depends on taking account of them.
Gender differences are indeed not the only differences that affect the success of sanitation projects and programmes: Most communities are quite heterogeneous. Differences between the rich, the middle class, and the poor must be taken into account when promoting better sanitation and hygiene. Occupational, religious and ethnic differences may also affect the types of facilities and practices that fit people's perceptions, means and conditions. Some groups stay for example on their land during the months of planting and harvesting. During this time, they continue to run risks when they practice openair defecation although they may practice safe sanitation habits at home. Other groups may have special requirements concerning design, location and/or sharing arrangements. Ecological differences also play a role. In dry areas, where water is scarce and has to be used economically, mothers cannot always practice handwashing for themselves and the children without being criticised by mothers in law or husbands for using too much water.

It is therefore important to:
Segment the communities into the different groups;

- Find out from each group what they practice, and why, throughout the year;
- Develop in close cooperation with the groups strategies that enables every group to measurably improve essential sanitation conditions and practices;
- Try out the strategies with the groups and adjust them as needed.

A gender approach is an essential, but not a sufficient, condition for sanitation programmes to succeed. Sanitation programmes only improve public health and well-being when a critical majority (that is, at least 80%, including especially poor people) in the communities can practice, and continues to practice, improved sanitation and hygiene behaviour. Sanitation programs need to be ongoing, self-sustainable (at least for the direct costs) and aim at sanitary practices that are sustained over time by a “critical mass”. The facilities are only a means; the end is the (measurable) good practice.

A lot can be done by being aware of the issues, having knowledge about gender and gender relations, having a positive attitude to reducing gender inequalities and being creative in seeking low-cost, culturally acceptable solutions to problems.
Discussing problems and possible solutions with the groups concerned helps. Often, people are so used to their situation that they are not aware of gender inequalities until someone else helps bring them out. Practical measures can be taken that require awareness and good communication and planning skills, rather than a lot of extra time, money and human resources:

- Information can be spread to women and men along channels and in forms that are adjusted to their different situations and interests (incl. poor women and men)
- Meetings can be held at times and locations that are convenient to women and men.
- Active participation of women in discussions and decisions is easier when:
    - women are invited and their participation is encouraged
    - they can sit together in a place from where they can hear and see as well as men
    - discussion is in the vernacular language, any outside information is translated
    - women (and men) get time to discuss the information during breaks

  - women can choose a spokeswoman for whom it is culturally acceptable to speak out, etc.
  - women can meet with the team for some time prior to the start of the meeting
  - participatory methods are used for situation inventory, analysis and decision making, e.g., pocket and matrix voting, picture card sorting, welfare ranking, etc.
- Women and men are enabled to make independent and informed choices of which women and men will deal with local planning, implementation and management of sanitation and hygiene improvements (informed = know which responsibilities, rights, authority, tasks, amount of work, knowledge, skills, training and compensation are involved).
- Both are enabled to consider and make informed choices on local technology and design, location, financing (incl. who will get what kind of support), sharing of implementation, maintenance and hygiene tasks, quality control. Scale models have proven useful (Centre, 2002).

7 Case studies in developing countries

7.1 COSAM, Comunidad Saludable Modelo, Lima, Peru

Contact:	SWO-docu (Contact person: Thomas Hefti) Swiss Welfare Organisation Stiftung für Strassenkinder Strehlgasse 11 CH – 8600 Dübendorf Tel. +41 1 882 36 20 Fax +41 43 355 24 59 www.swo-docu.org info@swo-docu.org APDES Asociacion de promocion y desarrollo social Isac Newton 7123 2do. piso Urb. Sol de Oro Los Olivos Lima, Peru Tel. (51-1) 533 7539 Fax (51-1) 533 5046 apdes@telefonica.net.pe

	SWO-docu. (2003). Gesundes Stadtquartier als Modell "COSAM, Comunidad Saludable Modelo" Collique-Comas, Lima, Perù. 4. Semester (01.03.2003 - 31.08.2003) (Dübendorf: SWO-docu), pp. 38. **SWO-docu.** (2004a). Gesundes Stadtquartier als Modell "COSAM, Comunidad Saludable Modelo" Collique-Comas, Lima, Perù. 6. Semester (01.03.2004 - 31.08.2004) und Auswertung der gesamten Projektdauer, Anhang "Projekt COSAM, Zusammenstellung Projektkosten" (Dübendorf: SWO-docu), pp. 3. **SWO-docu.** (2004b). Gesundes Stadtquartier als Modell "COSAM, Comunidad Saludable Modelo" Collique-Comas, Lima, Perù. 6. Semester (01.03.2004 - 31.08.2004) und Auswertung der gesamten Projektdauer, Anhang "Vom Projekt COSAM begünstigte Siedlungen in Collique" (Dübendorf: SWO-docu), pp. 2. **SWO-docu.** (2004c). Gesundes Stadtquartier als Modell "COSAM, Comunidad Saludable Modelo" Collique-Comas, Lima, Perù. 6. Semester (01.03.2004 - 31.08.2004) und Auswertung der gesamten Projektdauer (Dübendorf: SWO-docu), pp. 9. **SWO-docu.** (2004d). Gesundes Stadtquartier als Modell "COSAM, Comunidad Saludable Modelo" Collique-Comas, Lima, Perù. 5. Semester (01.09.2003 - 29.02.2004) (Dübendorf: SWO-docu), pp. 18.

System applied:	- Fat decantation, planted sand filter (papyrus) on household level - Sand filters with and without papyrus on community level

Level of application:	Collection of household greywater to irrigate two parks. Pretreatment system on household level and community level, use at community level

Project description:	The COSAM project started in September 2001 and ended in August 2004. The main goals of the project were improvements in the field of settlement hygiene and environment. 25 settlements benefited from the project. APDES is the implementing agency in Peru, SWO-docu coordinates the financing. The project is financed by SWO-docu, SDC and the city of Dubendorf. SWO-docu applied for the financial support by SDC (Swiss Agency for Development and Cooperation). An extension of the project is likely. General results of the project: - Sensitisation and mobilisation of the population - Advanced training of community representatives - Realisation of different infrastructure modules in the field of environment and settlement hygiene - Operation of infrastructure modules - Participative planning of community development and environmental aspects - Organisation of a committee responsible for environmental questions The infrastructure modules encompass the following activities: - Greywater treatment and reuse for irrigation and reforestation - Building of latrines - Solid waste collection - Improvement of drinking water quality - Vegetable house gardens - Reforestation of slopes Two project parts involved greywater: 1. Irrigation of a park 386 inhabitants of the settlement “Lomas the Collique” profit from this project part. Their hand basins are attached to a greywater treatment system that was built in February 2003. The pretreated greywater is used for the irrigation of the park “Las Casuarinas”.

Figure 12: Park „Las Casurinas“, irrigated with treated greywater

The washing troughs of each house are attached to a house filter, consisting of (a) an oil and fat decantation and (b) a sand/ gravel filter planted with papyrus.

The greywater is stored centrally; before the water reaches the reservoir there is a two level treatment basin, consisting of (a) a sand/ gravel filter and (b) a planted sand filter with papyrus.

Figure 13: Papyrus plants growing in a bio filter for greywater treatment

2. Reforestation

The second project component uses the collected greywater of 4 households for the irrigation of a reforestation area on a slope in the settlement of Las Lomas.

Figure 14: Biofilter for the slope irrigation of the settlement of Las Lomas

	 **Figure 15: Slope reforestation, irrigated with greywater** For those two greywater project components a project committee is responsible which will supervise the greywater part after finalisation of the project.
Experiences:	- Users have to stop to use the water to sprinkle the streets when they are dusty, because if they do so there is not enough water for the papyrus plants. - In the 5th semester there was too much fat and oil in the greywater. An information campaign and home visits to the households sensitised the families and led to a satisfying water quality. - Problems are related to the care for the fat decantation unit, the cleaning of the filter material and the replacement of papyrus plants, tasks that have to be performed regularly in order to guarantee the proper functioning of the system (talk with Mr. Hefti). - For the population the greywater treatment system is an interim solution, their final goal is to be attached to a sewage treatment system (talk with Mr. Hefti).
Costs:	Money spent in the 6 semesters of the project (9.2001 – 8. 2004) 186'370.00 US$; 282'542.75 Sfr; 117'542.75 by SWO-docu 120’000 by SDC and 45’000 by the city of Dübendorf For the exact account see SWO-docu, 2004a

7.2 American Pavillion Auroville, India (University of Washington)

Contact:	Chuck Henry, Research Professor University of Washington - Bothell 144 UW1 Box 358530 Bothell, Washington 98011-8246 Telephone: (425) 352-3587; FAX: (425) 352-5233 Email: clh@u.washington.edu

References:	http://faculty.washington.edu/clh/india/india.html Mail Chuck Henry, 7. July 2004

System applied:	Grit chamber, reed beds (planted sand filter) and irrigation beds (bananas)

Level of application:	Designed for a visitors dormitory with probably 12 beds

Project description:	This project is part of the Bachelor of Science in Environmental Science at the University of Washington. It was a comprehensive course on Sustainable Development during Winter quarter 2002. Students had the option to get credits while doing courses at the international community Auroville in India. The main object was wastewater and greywater. The program introduced students to sustainable development practices. Much of the learning process for the students in this particular program was through documentation of the practices used in Auroville. Students researched what had and had not worked. The duration of the program was 8 weeks, 37 students and TA's and 5 faculty members participated. The whole project encompasses a greywater treatment system, composting toilets, a water harvesting system and a solar energy system. One of the most important parts of the program was the demonstration of new concepts. In this case, the students came to Auroville with an idea about how the wastes and rainwater harvesting should be handled. Yet, some of these practices had been used in the past and failed, so there was a prejudice against them. Through student perseverance, they convinced Aurovillians that these systems could indeed work if they are properly constructed and cared for. The planned facilities included separate facilities to handle the liquid wastes and the solids wastes. Water has always been in short supply in the southern part of India, and it is becoming more so. So the goal was to both reduce use, and to recycle the effluent form treatment. So, they chose to use composting toilets, and then handle greywater with minimal treatment.

The treatment system is actually over designed. This gives the option of combining greywater and blackwater treatment in the future.

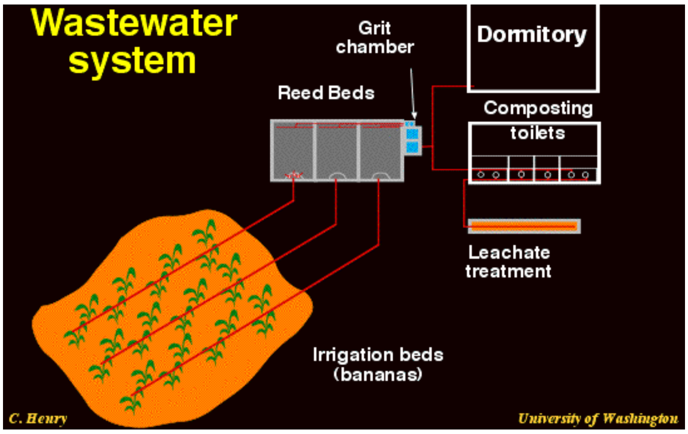


Figure 16: Wastewater treatment system of Auroville

The objectives for this system were:

<u>To minimize water use</u>: Composting toilets eliminate almost 30% of the typical domestic water use. It also caries an even greater percentage of the solids flow. Additionally, they used low flow faucets and showerheads.

<u>To reuse the water, nutrients and organic matter:</u> This greywater system will be used to irrigate and fertilize a banana plantation (see photos and figure 16).

<u>To demonstrate new approaches that can be used beyond the project boundaries:</u> Wastewater management is a tremendous challenge in these areas. The project responsibles wanted to have a good, inexpensive system that a homeowner could also install. A number of the Tamil workers expressed interest in the system that was built. As they worked beside the people from the university throughout the construction process, they can use this experience in their own village.

<u>To open the opportunity for potential studies:</u> This system has sampling points at various parts of the system to study the quality of the treated greywater. These are in the grit chamber, at all outflow ports of reedbeds, and at the end of the drainfield.

Figure 17: Greywater treatment system

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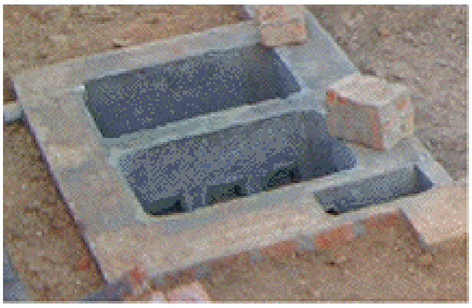
<tr><td></td><td>
Figure 18: Grit chamber

Figure 19: Planted reed beds

Figure 20: Bananas planted in drainfield</td></tr>
<tr><td>Experiences:</td><td>The system is very much over designed, because the students got too ambitious. But this brings also the chance to convert the system into a combined blackwater/ greywater system if needed sometimes in the future. The other unfortunate thing about this system is that it has actually not been used yet. It was built it in the winter of 2002, and there still isn't enough water for people to stay there. (Mail Chuck Henry 7.July 04)</td></tr>
<tr><td>Costs:</td><td>No information about costs could be found.</td></tr>
</table>

7.3 Xochitepec Rehabilitation Centre for Children, Mexico (University of Washington)

Contact:	Chuck Henry, Research Professor University of Washington - Bothell 144 UW1 Box 358530 Bothell, Washington 98011-8246 Telephone: (425) 352-3587; FAX: (425) 352-5233 Email: clh@u.washington.edu

References:	http://faculty.washington.edu/clh/mexico/mexico.html Mail Chuck Henry, 7. July 2004

System applied:	Black water goes to septic tank Pretreated black and fresh greywater go to a bioreactor, after treatment, effluent is distributed to mulch beds

Level of application:	Rehabilitation centre for children

Project description:	This project is part of the Bachelor of Science in Environmental Science at the University of Washington. It was a comprehensive course on Sustainable Development during Winter Quarter 2003. Students had the option to get credits while doing courses in Mexico. One object was to find alternatives for a community wastewater system. The focal point of the whole program was the construction of a "Centro de Rehabilitación para Niños" and the supporting infrastructure includes on-site waste management, water harvesting and solar energy. The approach was to keep black and grey water separate, and reuse each after appropriate treatment. The black water goes through a septic tank, then combines with the grey water and proceeds to the bioreactors. After treatment, the effluent is distributed to mulch beds. In the mulch bed water reuse area multi-functional plants will use the water and nutrients, and even potentially provide a food crop (such as bananas). It doesn't make sense to treat the grey water to the extent that black water is treated, as it is not as contaminated. But it does make sense to combine the two after treatment, as black water is nutrient rich, while grey water is nutrient poor and can dilute the black water.

Figure 21: Building zapatas

The objectives for this system were:

To design a system that is both economical to build and to operate and maintain: Citizens in the City of Xochitepec are not able to support a high cost of O&M, even though the construction costs were picked up primarily by the Federal government.

To fit the treatment plant into the "economically" available area: In many of these communities planning for a future wastewater treatment plant was never a consideration. Land has to be found and obtained at the low point of the sewer line. This can be both a time-consumptive and expensive process.

To demonstrate new alternatives: Wastewater treatment has been around a long time, and excellent systems exist. However, there is increased interest in "natural systems". Some of these systems were demonstrated; if not as the primary facility, as an additional component to a traditional approach. In this case, a small natural wetland was proposed to be a "polishing pond" to handle a portion of the flow. This system may become a future year's project.

To handle the particular conditions of the area: The sewage collection system evolved over a number of years, and was constructed by both city and citizen efforts not necessarily consistent with an overall plan. As such, there is varying quality of construction, as well as connections of storm flows. At the intensity of rainfall events, the amount of water entering the sewage system can overwhelm a typical treatment plant. A design must be able to accommodate this problem.
Secondly, the collection systems rely upon existing stream channels or open ditches to transport the sewage away from the end of the pipe. Construction of the collection infrastructure could be potentially more expensive than the treatment plant. This suggests the use of a number of smaller plants as opposed to a central plant.

To plan the construction of a system in a fairly short time period: Government funding is normally subject to a defined time period, both because funding cycles are finite and political climates change. Often when money is not used, it is lost. In this case, the goal was to design a plant that can be constructed in a short time.

	Use the government's design criteria: Water use in Mexico is significantly less than in the US for a number of reasons, in particular due to scarcity. However, since they were not able to measure flow rates over a period of time, they had to use the estimated use and estimated population contributing to the system. This may still overestimated total flow rate, but it very possibly can provide a buffer for future additions to the system. One of the most important parts of this program was the demonstration of new concepts. As many of those practices are new for a community, they wanted to make them highly visible to the people.
Experiences:	"It does work very nicely." (Chuck Henry)
Costs:	No information about costs could be found.

7.4 Sustainable Practices in Mastatal, Costa Rica (University of Washington)

Contact:	Chuck Henry, Research Professor University of Washington - Bothell 144 UW1 Box 358530 Bothell, Washington 98011-8246 Telephone: (425) 352-3587; Fax: (425) 352-5233 Email: clh@u.washington.edu Tom McDonald, Lecturer: tiburon@u.washington.edu

References:	http://faculty.washington.edu/clh/costarica/costaricab.html Mail Chuck Henry, 7. July 2004

System applied:	Mulch bed system, reuse for crop production

Level of application:	Rancho Mastatal, lodge, centre for environmental learning and sustainable living

Project description:	**Project 1: Summer 2003, June 18- July 9, 2003** This project is part of the Bachelor of Science in Environmental Science at the University of Washington. It was a comprehensive course on Sustainable Development during Summer Quarter 2003. Students had the option to get credits while doing courses during summer in Costa Rica. One object was wastewater and greywater. The program introduced students to sustainable development practices and included a service-learning component in which students assessed the impacts of development on the environment and communities in rural Costa Rica. Possible infrastructure projects to realize the idea of sustainable development were: developing solar passive or active energy systems, composting food and other wastes, greywater use, and rainwater catchments. <u>Project Site</u> Mastatal is a small (pop: 160) agricultural "campesino" community located approximately 2.5 hours south/ southwest from San Jose in the Pacific lowlands of central Costa Rica. It is adjacent to the La Cangreja National Park (Cerro Cangreja). La Cangreja was designated the newest national park in Costa Rica in June 2002. The park contains the last remaining primary forest in the ecotonal region between the pacific lowlands and the central highlands. The proposed project for the first year was to design and construct a greywater mulch bed system to reuse the water and nutrients for crop production at Rancho Mastatal, an environmental learning and sustainable

	living centre. But it was just possible to theoretically plan a greywater system and instead a composting toilet was built. **Project 2: Summer-Fall 2005: August 29 - September 28** In 2005 they want to build a greywater system as it was planned during the first trip.
Costs:	No information about costs could be found.

7.5 Reedbeds in Monteverde, Costa Rica

Contact:	Mr. Stewart Dallas unep-ietc Environmental technology centre [etc] Murdoch University South street Murdoch WA 6150 Western Australia stew@mvinstitute.org

References:	http://wwwies.murdoch.edu.au/etc/pages/news/sdalas03_01.html http://www.mvinstitute.org/r/t/

System applied:	Constructed wetlands, submerged flow reedbeds (planted sand filter)

Level of application:	Multiple levels, from single household to a four household system

Project description:	Monteverde, in northwest Costa Rica, is famous for the Monteverde Cloudforest Reserve. The number of visitors to the Cloudforest Reserve alone has jumped from some 300 in the early 1980s to over 60,000 in 2003. The total number of visitors to the larger Monteverde area is estimated at more than 200,000 annually. This development caused significant problems with sanitation. Stewart Dallas lives in Costa Rica since March 2000 and is making research for his PhD there. In Monteverde, greywater makes up around 70% of the total wastewater produced by a typical home, which equates to about 600 litres of greywater per day per household. With over 650 homes now in the area, this equates to some 390'000 litres per day of raw greywater entering the environment. Mr. Dallas concentrated on trials on reedbeds to treat this greywater. Briefly, reedbeds are a trench at ground level which is lined with either plastic or clay, filled with gravel and planted with reeds - a simple hydroponic system. He decided that submerged-flow (or sub-surface flow [SSF]) reedbeds would be the only viable type: With an SSF type reedbed the water level is always at least 10 cm below the gravel surface which means that the greywater is never visible, there are no odours, children and dogs can't come into contact with the greywater and most importantly mosquitoes cannot access the water to breed. Dengue is a problem in Costa Rica. The second problem was to find a species of reed that was non-invasive, native if possible and would survive in greywater. Many constructed wetlands in Europe and Australia use the common reed *phragmites australis* which, apart from being uncommon in Costa Rica, is also

	considered a noxious weed. He finally found a species locally known as 'Job's Tears' or Lagrimas de San Pedro in Spanish (Coix lacryma-jobi) which works well and is also providing a seed which is widely used in local handicrafts. While not native to Costa Rica, Job's Tears is considered to be a 'naturalised' species by local botanists and is non-invasive.  **Figure 22: Reedbed treating greywater from four homes in Santa Elena near Monteverde.** The community response to this work has been very encouraging and so far five reedbeds have been installed in the area ranging from single households, to a café, a system treating the greywater from four homes and also one treating septic effluent. All of these systems are monitored for water quality parameters such as nitrates, phosphates and faeces. 12 mini-reedbed cells that were established in order to develop a model for predicting performance are also monitored. Together with the four- household- system he developed an environmental service contract whereby the users pay a nominal fee to have their greywater treated privately; the first of its kind in Costa Rica.
Experiences:	"As with the introduction of any new technology there needs to be consideration of the cultural, economic and environmental impacts amongst others, particularly if it is to be sustainable. Sustainability and improved health outcomes are key to my research although quantifying these two parameters is much easier said than done." (Stewart Dallas)
Costs:	No information about costs could be found.

7.6 Sawan Canal Community, Bangkok, Thailand

Contact:	Thai Community Foundation (in Thai!) 2044/18 New Petchburi Rd. Huay Khwang, Bangkok 10320 Thailand Tel: +66 2 716 5610-11 Email: contact@chumchonthai.or.th http://www.chumchonthai.or.th/ Contact person Sawan Canal (English-speaking): Mr. Vichai Suksawad Mobile phone: +66 1 720 4330

References:	**Montangero, A.** (2003). Visit of the Sawan Canal Community (Bangkok) – October 03, pp. 2.

System applied:	Septic tank for the blackwater Two-bucket greywater system consisting of a filter bucket and a coal bucket.

Level of application:	Household (about 9 people per household)

Project description:	The Thai Community Foundation is working with communities living in illegal settlements in Thailand. They promote networking/ exchange of information between the different communities and support environment improvement projects. They are now working together with about 1000 communities. The Foundation is financially supported by DANIDA. It counts about 40 staff (in the whole country). The Thai Foundation is linked to CODI, the community organisation development institute, an independent institute under the Ministry of Human Development. The Thai Foundation works with the communities to find out what they would like to improve, and then it advises them on how to improve. The Foundation tries to learn from solutions developed in different communities and brings this knowledge to other communities (local knowledge). A wastewater treatment plant (septic tank and filter) was designed by a University in the North of Thailand for one of these communities. For the Sawan Canal Community, it is planned to build septic tanks under the walkway (along the canal). People living in this community came to Bangkok about 20 years ago. They first settled on the land nearby the canal but were forced to leave the land by the land owners. Most houses of the community are now built on the canal (about 40 on the canal and about 8 on the land nearby the canal). There are about 1500 such illegal settlements in Bangkok.

Figure 23: Houses of the Sawan Canal Community

There is no water supply. They use the canal water for washing and bathing. They buy drinking water. It costs 10 baht/ bucket (20 l), 300-400 baht/month/household. They do not collect rainwater; the reason mentioned was that roofs are not clean. Most houses are equipped with septic tanks but black water is reportedly directly released to the canal through holes in the tanks. People usually use water for anal cleansing.
Most houses are equipped with a greywater treatment system, a “grease trap system” consisting of two buckets. Washing water flows through a screen in the first bucket on which floating and coarse materials are retained. The water flows then through a pipe in a second bucket filled with coal. The effluent is then released to the canal. Cost of the bucket amount to 200 baht. Coal is reportedly replaced every few months.

Figure 24: Two bucket greywater treatment system

The residents are connected to the electricity network (one electricity meter for the whole community). Solid waste is recycled or burnt. Main diseases are reportedly skin diseases, especially during the dry season, and eye irritation. Diarrhoea does not seem to be a common disease.

The community is willing to invest money (e.g. grease trap tanks) but they are investing in inefficient solutions (treatment of grey water but no treatment at all of black water yet). They are thinking of building septic tanks, but then they will face the problem of septage management.

Costs:	Buckets: 200 Baht = 5 USD

7.7 Urban and suburban sewage disposal systems in Sri Lanka

Contact:	PhD by: Eusebius Joseph Harindra Corea Supervising professor: Professor Duncan Mara The University of Leeds School of Civil Engineering Leeds, LS2 9JT United Kindgom. Tel: +44 (0) 113 343 2276 Fax: +44 (0) 113 343 2243 d.d.mara@leeds.ac.uk

References:	**Harindra Corea, E.J.** (2001). Appropriate Disposal of Sewage in Urban and Suburban Sri Lanka. In School of Civil Engineering (Leeds: The University of Leeds), pp. 270.

Systems applied:	Septic tanks; Anaerobic filters; Horizontal flow reed beds; Infiltration- percolation beds; Vertical flow planted gravel filters

Level of application:	Individual houses; Housing schemes; Tourist hotels; Schools; Daytime occupancy buildings

<table>
<tr>
<td>Project description:</td>
<td>
This study was aimed at identifying, adapting and evaluating appropriate, cost-effective technologies in the field, for urban and suburban sewage disposal systems in Sri Lanka. Septic tanks, anaerobic filters, horizontal flow reed beds, infiltration- percolation beds and vertical flow planted gravel filters were adapted and evaluated, at field- scale, as potential technologies to be used as primary, secondary, and tertiary unit processes.

The categories considered were individual houses, housing schemes, tourist hotels, schools and halls of residence, and daytime occupancy buildings. A total of 36 full-scale treatment systems were designed, spanning all of the categories under consideration for real situations in the field. 28 full-scale systems were built and evaluated for performance, reliability of operation and treatment, user satisfaction and cost. Maintenance issues and appropriateness of application were found to be key factors in the medium to long-term success of the systems as well as design issues.

- Anaerobic filters were found to be robust and reliable for all the categories under consideration for secondary treatment of septic tank effluent for surface discharge, or for reuse after tertiary treatment.


Figure 25: Entrance and driveway of the Devon Rest Hotel during construction of the anaerobic filter unit

- Horizontal flow reed beds and vertical flow planted gravel filters were found to be applicable for secondary treatment of septic tank effluent in certain, specific situations.

- Percolation beds and vertical flow planted gravel filters were found to be appropriate and cost-effective as tertiary treatment unit of effluents for on-site reuse for gardening, toilet flushing and vehicle washing.
</td>
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</table>

	 **Figure 26: The vertical flow planted gravel filter unit of the Swiss Residence Hotel after commissioning** A case has been established for the cost-effectiveness of these systems for on-site reuse, particularly for tourist hotels, with a potential cost recovery of 13 percent of capital cost per annum. Guidelines for the appropriate selection, design and implementation of these systems are proposed for each of the target categories.
Costs:	The 28 systems were evaluated for cost-effectiveness.

7.8 Greywater treatment using trickling filters with reuse for Peri-Urban Horticulture (West Bank, Palestine)

Contact:	Dr. Abdelatif Mohammed Palestinian Agricultural Relief Committee (PARC) PO Box 25128 Shufat Jerusalem

References:	The International Development Research Centre http://network.idrc.ca/ev.php?

Systems applied:	Trickling filters

Level of application:	10 – 15 homes, but the objective of the project is to standardise means and methods for the up-scaling and replication of onsite greywater treatment plants for decentralised aggregates of 15 – 20 homes.

Project description:	**Objective** The main objective of this study was to standardise the means and methods for the up-scaling and replication of onsite greywater treatment plants for decentralised aggregates of 15 to 20 houses. **Description** This pilot project optimised the design of small-scale trickling filters for the treatment of greywater for reuse in home gardens in hilly, low-density peri-urban areas of the West Bank, for presentation to policy-makers and other donors. The individual or small collective (10-15 homes) systems were built from recycled shampoo containers and used local materials such as wadi gravel or waste such as crushed plastic bottles as filter media. The treated greywater from an operating system was used for irrigating any products in home gardens, including raw vegetables. The goal of this project was to have the trickling filter accepted by the Palestinian National Authority and implemented across appropriate areas of the West Bank, in order to reduce the amount of total waste (black and greywater) contaminating the sensitive aquifers in the West Bank and help address the diminishing fresh water availability per capita in the region. The systems could also help Palestinians, often affected by border closures, maintain a secure food supply. **Gender aspects** This project was co-led by the Gender Division and the Environment Division at PARC and was working explicitly with women. Women approached the Palestinian Agricultural Relief Committee (PARC) for help in designing and building greywater recycling systems for use in their home gardens. The women's unit helped select the villages where the systems would be placed and developed a pre- and post-installation questionnaire.

	The women's units are more interested in individual home garden systems than the collective systems because they tend to have more control over the benefits when their system is closer to home and at a smaller scale. In other words, when the project remains at the household level, women tend to have control over the resources and small amount of income they can derive from selling the produce they produce by reusing wastewater. Once the projects increase in size to the collective systems, the tendency is for men to take a greater interest in the project as the potential for more resources increases. Thus women fear loss of access to resources and control over the benefits. The Gender Division has not accomplished as much within this project as it would have hoped, as it did not participate to the same degree as the Environment Division. This highlights the challenge that researchers often face in achieving gender-disaggregated work.
Experiences:	- PARC refined the greywater treatment design by putting vents on septic tanks to reduce odour and added an aerobic sand unit downstream for polishing the effluent and ensuring that the trickle irrigators do not clog. - Other agencies (Dutch Embassy, Spanish Cooperation, European Union) have been sufficiently impressed with the systems and PARC's increased capacity to install approximately an additional 150 units. - Septic tank pump-out cost savings are up to a maximum of $400/year. - Helped create jobs – because of the two-year payback period, homeowners are beginning to hire masons and plumbers to install greywater reuse systems without any PARC involvement. - Achieved an average of 56% greywater recovery in each home system. This reduces pressure on an overloaded and polluted environment – septic tanks, aquifers and sewerage systems.
Costs:	355 340 CAD = 287 795 US$

7.9 Greywater treatment using septic tanks and reuse for home gardens, Tufileh, Jordan

Contact:	Murad J. Bino Project Leader Inter – Islamic Network on Water Resources Development and Management (INWRDAM) P.O. Box 1460 Jubieha Amman Jordan Email: inwrdam@nic.net.jo http://www.nic.gov.jo/inwrdam/

References:	The International Development Research Centre http://network.idrc.ca/ev.php **Al-Jayousi, O.R.** (2003). Greywater reuse: towards sustainable water management. Desalination **156 (2003),** 181-192.

Systems applied:

- Pre – treatment in a storage tank (160 L barrel) and with a greywater kit (it is not explained of what it consists). The tank, acting as conventional septic tank, removes oil, grease and settable solids (see Figure 27)
- A collective secondary treatment was designed. It is not explained of what it consists

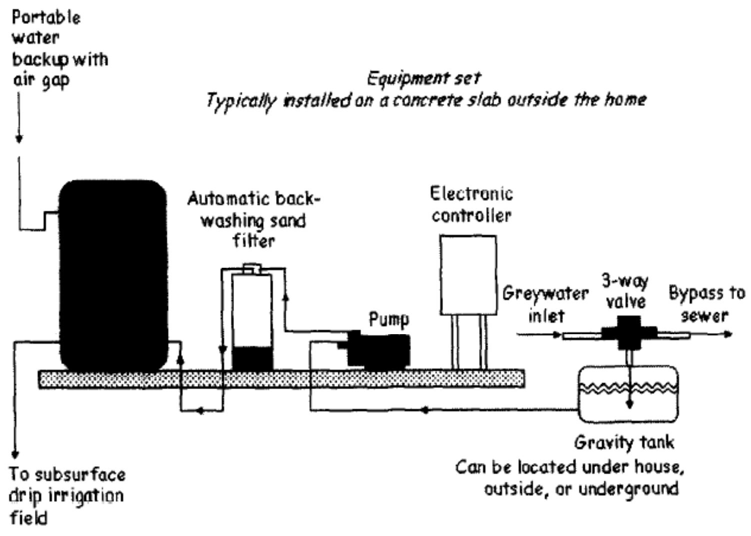

Figure 27: Automated greywater system used in Jordan

Level of application:	Household level 50 poor peri – urban families were funded in this project

Project description:	**Objective** The objective was to optimise and validate a system for reusing greywater in home gardens in Ein Al-Baida, Jordan. **Description** This project builded on a permaculture pilot and greywater reuse project (PPP) in Tufileh, Jordan that provided a revolving fund to help approximately 50 poor peri-urban families recover household greywater to grow fruit and vegetables. An evaluation of the project indicated that it has helped families preserve valuable freshwater, achieve greater food security and generate income through sales of produce. The project aimed to optimise the PPP with a view to its wider implementation in Jordan and elsewhere in the region. Efforts have been made to increase the greywater recovery rate, so that crops requiring more water can be irrigated; to promote the installation of pipes and storage tanks by those willing to pay for them; to expand environmental education; and to put in place incentives to use potassium-rather than sodium-based soaps and detergents. To date, the environmental impact arising from the use of untreated greywater has been minimal. It could become significant over time, however, if water quantities increase or water is used on soils of high salinity or alkalinity. INWRDAM has carried out an evaluation of the use of simple treatment devices such as screens in sinks, grease traps and trickling filters. Residents have been encouraged to alternate occasionally between greywater and harvested rainwater irrigation, and to use drip irrigation and mulches to improve water efficiency. Finally, the community has also been encouraged to plan salt-tolerant crops such as olives and pistachios. **Gender aspects** The team observed that women are "heavily involved" in the training workshops addressing the organisation and management of the systems, irrigation processes and permaculture projects. It is clear from the detergent levels in greywater effluent that the poor, who can ill afford it, are using far too much detergent when washing clothes. This is partly because the instructions on the shampoo, dishwashing liquid and laundry detergent are meant to sell more detergent. Female staff on the project have focussed on discussing issues with women, predominantly responsible for the washing, including using demonstrations to show that diluting detergents, particularly shampoos, cleans just as effectively as the manufacturers' "recommended" amount.
Outputs and experiences:	**Convenience and safety of greywater recovery** - 25 greywater kits, two 160 L barrels designed to pre-treat water to remove oil and grease, have been distributed. - The design of the INWRDAM system improves upon a design by the Palestinian Agricultural Relief Committee (PARC): the tanks are buried to 50% of their height and the distribution tank is an integral part of the system instead of being suspended. Injuries that could result from the structure being tipped over are thus avoided.

	- Preliminary results indicate that magnesium and potassium levels in the greywater effluent from the kits are in the range of 10-20 mg/l, which meets the standard for irrigation. - Results are showing an effluent quality that meets the standard for unrestricted irrigation. This is a promising sign as the anaerobic processes are not yet mature and effluent quality should improve over time. - A collective secondary treatment system is being designed. It will treat the pre-treated water, resulting in water suitable for unrestricted irrigation. - Social acceptability of greywater reuse has been high. In fact, there is an overwhelming demand by inhabitants for the installation of these kits in their homes. - Wudu (Ablution) water from the mosque, which generally does not contain any soaps or detergents, is recycled for landscaping on the mosque grounds as well as for irrigating olive trees. **Environmental impact, cost-effectiveness and necessity of greywater reuse** The benefit-cost ratio of practising greywater reuse is high: on average, the families who are participating in this project have a benefit-cost ratio of 5:1. - More than 90% of the beneficiaries are willing to contribute to the capital cost of the system. - 50% to 60% greywater recovered per household, approaching maximum theoretical level of 80%. - 5 JD to 10 JD (US$8 to $15) savings on water bills per quarter per household. - The community has been able to offset food purchases because the reuse of water has led to increased crop production, and income has been generated by selling surpluses. - INWRDAM designed and built a mould for rubber seal that reduces costs for connecting barrels by 75% (from 5 to 20 US$) as the flexible rubber O-ring can be used with cheaper PVC rather than UPVC pipe. - Increasing efficiency by using cut-up recycled plastic irrigation piping as filtering media rather than gravel, which is cumbersome to transport and requires manual labour. - The creation and marketing of organic soaps by Dr. Omar Jabay, a specialist on detergents, who has substituted potassium for sodium in the chemical process. (Sodium-based soaps increase the alkalinity and salinity of greywater, which will, in turn, harm salt-sensitive crops. Potassium, on the other hand, acts as a fertilizer.) **Gardening and permaculture practices** - INWRDAM has developed a greywater distribution and drip irrigation system and trained the beneficiaries on how to use them. - INWRDAM demonstrated to the beneficiaries how to design their gardens in separate irrigation units in order to improve methods of water application. - A series of workshops have been held on topics such as: better irrigation requirements; reduced application of pesticides and fertilizers; environmental management; diversifying cropping

	patterns. - Greywater use impact assessment on crops, soil and groundwater is being monitored with support from the Ministry of Agriculture via the National Centre for Agricultural Research and Technology Transfer (NCARTT). **Local capacity building with regards to safety and efficiency of greywater reuse** - Local plumbers and electricians have been trained to build their capacity in greywater separation, treatment and reuse. - Several workshops have been held on topics such as: - Operation and management of the greywater filtration system and permaculture techniques. Attended by community leaders, women and potential beneficiaries. - Environmental and social parameters of greywater quality. Basic environmental concepts such as water pollution and material conservation were presented. - Detergent use. More detergent than necessary is being used when washing clothes. It was shown that diluting detergents, particularly shampoos, cleans just as effectively as the manufacturers' "recommended" amount. - Draft poster for public awareness activities to encourage greywater reuse to conserve water, increase food production and generate income. **Policy change and improvement of greywater reuse in Jordan** - Proposed modified version of the chapter on the building code related to sanitary conditions so that houses are built to allow occupants to practice greywater reuse without the need for further plumbing modifications. - Many local and international organizations working in Jordan have expressed interest in adopting the system. - The Water Authority of Jordan (WAJ) subcommittee on wastewater reuse set up a national committee to formulate greywater reuse guidelines.
Costs:	200 000 CAD = 161 983 US$

7.10 Greywater treatment using trickling filters and reuse of treated water in home gardens in West Bekaa, Lebanon

Contact:	Boghos Ghougassian Coordinator Middle East Centre for the Transfer of Appropriate Technology (MECTAT) Tarazi Building, Labban St., Hamra P.O. Box 113 5474 Beirut Lebanon

References:	The International Development Research Centre http://network.idrc.ca/ev.php?

Systems applied:	Trickling filters Filter media is made of PET bottles

Level of application:	Household level The filters were implemented in 30 homes

Project description:	This project is currently under way (duration 2002 – 2005). **Objective** The objective is to test a system for reusing greywater in home gardens in a cluster of towns in the West Bekaa region in order to help the peri-urban poor in Lebanon preserve fresh water, increase food security and generate income, while helping to protect the environment. **Description** This project will test a system for greywater treatment and use in home gardens in several towns in West Bekaa. Initially, it involves the implementation of greywater treatment systems using trickle filters in 30 homes. The results will then be extended throughout a five-community cluster of surrounding villages. Ultimately, the hope is that the use of greywater will become a significant resource in urban agriculture projects in order to improve nutrition, food security, and the overall income of poor households. The Palestinian Agricultural Relief Committee (PARC) and the Inter-Islamic Network on Water Resources Development, both of which are involved in IDRC-supported wastewater reuse projects in the region, will participate. The aim is to develop a regional wastewater reuse network where best practices and lessons learned can be brought to bear on public policy. **Gender aspects** Among this project's four major thrusts is to study the socio-economic impacts of greywater use, especially those related to gender. The five towns within the project have four different ethnic and religious backgrounds. The community-based organization involved in this project has worked successfully with these different groups and is sensitive to the

	different cultural traditions of the towns. Reusing any waste – even something like greywater, which can be very safely reused following very simple guidelines – sometimes raises objections. Social habits and perceptions with respect to water use practices and use of soaps and detergents will be discussed separately with women and men of the communities. In the West Bekaa, women manage the household budget. They also take most of the responsibility for the health and nutrition of the family. Whereas in other countries in the region, similar projects have involved the whole family, this project includes a specific objective to identify and incorporate relevant socio-economic issues. This includes those linked to gender and will involve the use of gender-disaggregated labour schedules for gender and social analysis. MECTAT itself is a multi-ethnic organization and understands that the roles of women and men on the project are likely to vary within the different ethnic and religious communities. It has also engaged a sociologist to study the socio-economic and gender issues.
Provisory outputs and experiences:	- Significant community participation. - Visits and cross-fertilization of ideas with other projects in the region.
Costs:	242 780 CAD = 196 631 US$

7.11 Ecological Sanitation (ecosan) in Koulikoro/Mali

Contact:	Dipl.-Ing. Christine Werner Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH Ecosan Postfach 5180 65726 Eschborn Telefon: ++49 (0)6196 / 79-1740 Fax: ++ (0)6196 / 79-801740 Email: ecosan@gtz.de And Dr. Ing. Martin Oldenburg OtterWasser GmbH Ingenieurgesellschaft für integrierte Siedlungstechnik Engelsgrube 81 23552 Lübeck Telefon: ++49 (0)451 / 70200-51 Fax: ++49 (0)451 / 70200-52 Zionskirchstr. 8 10119 Berlin Telefon: ++49 (0)30 / 3100 4652 Fax: ++49 (0)451 / 3101 4654 Email: info@otterwasser.de

References:	GTZ Ecosan www.gtz.de/ecosan.html

Systems applied:	*An* ecosan-*installation was implemented, based on the traditional latrine-system used in Mali:* - Two-chambered system for the treatment (drying) of faeces - Separated drain for urine - Drain for greywater coming from showering and washing and leading to the treatment plant *Treatment plant:* Filtration through a sand and gravel column covered with vegetation (species unknown) and subsequent use for watering a vegetable garden

Level of application:	This project was conceived for a household level. Houses in urban regions of Mali are built on parcels having a surface of 15 – 20 x 25 m. Walls delimit each parcel. There are on average 10 people of different generations living on a parcel.

<table>
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<td>Project description:</td>
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Koulikoro, a regional capital of Mali, has about 26’000 inhabitants. The different districts of this city are widely dispersed. This gives them a village character. Households consist of a parcel of 15 – 20 x 25 m, often delimited by walls. Parcels are like distinct units, each having a different court size.
There is usually one latrine per parcel where showers, spatially separated, are also taken. Seat-less lavatories (toilettes turques) are widespread in West Africa. Faeces are collected separately from the rest of wastewater (urine, shower and washing water) in an underground septic pit. Once this pit is filled, it is:

1. Emptied if there isn’t enough place for a second latrine. This can imply serious hygienic dangers if security aspects aren’t considered.
2. Closed and a new one is dug elsewhere on the parcel.

The principal subsistence comes from agriculture.

The power of this project is to consider the typical urban structure and the deep-seated, religious habits of population as regards of hygiene (wet anal hygiene) for the implementation of a new sanitary system.
The ecosan-installation is an extension of the traditional latrine system, where two different partial flows (faeces and all other waste waters) exist. It is composed of three partial systems:

1. Drying of faeces
A two-chambered system permits the collection, drying, storing and sterilisation of faeces. Each chamber is alternatively turned over once a year. Ashes are added after every use of the seat-less lavatory to enhance the drying process and avoid formation of odours. An opening allows the inspection of the drying process and the emptying of the chamber. It is made of a black-tainted metallic hatch that is exposed to the south. Each chamber is provided with an airing pipe.
2. Draining and collection of urine
Urine is led to a collecting tank through a drain or pipe.
Field experiments showed enhanced plant growth (comparable with mineral fertiliser treatment) in maize cultures when liquid urine was mixed with compost and combined with dried faeces. But the best results were obtained by applying a mix of mineral fertilisers and organic components (dried faeces, liquid urine and compost).
3. Draining and treatment of greywater (shower and washing up water) for subsequent use in vegetable gardens
The shower and washing up water is led to a greywater treatment system (see Figure 28). Two different systems were experimented:
“Système Ecologique de Traitement des Eaux Grises (SETEG-Jardin)”
Greywater is filtered through a sand, carbon and gravel column and then used for sub-surface irrigation of little vegetable gardens. Buried, perforated pipes ensure sub-surface irrigation. With this system, there isn’t any need to water plants.
“Système Ecologique de Filtrage des Eaux Grises (SEFEG-Jardin)”
Greywater is first decanted and then filtered in a sand, carbon and gravel column. The treated water is collected in a reservoir for subsequent watering of vegetables and trees.
These systems had a great success with women, because they allowed a securer supply of vegetables and economies on the familial budget.
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	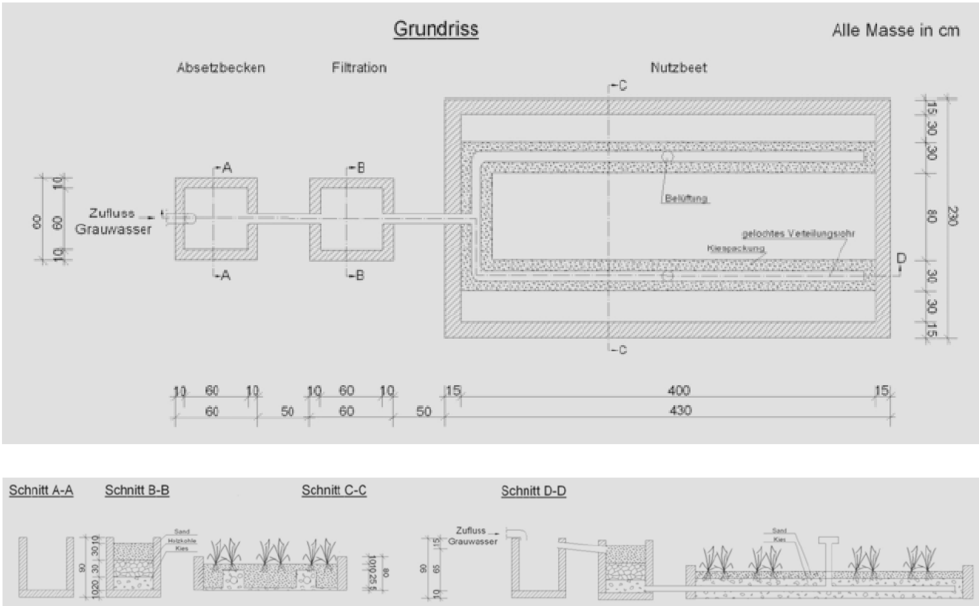 **Figure 28: Plans of the greywater treatment system**
Experiences:	- The treatment and utilisation of greywater in vegetable gardens are an appropriate solution only when there is enough available place  **Figure 29: Fertilisation experiments. The fertilisation with 50 % compost enriched with urine + 50 % dried faeces (C) and 50 % compost enriched with urine + 50 % mineral fertilisers (D) showed the highest biomass growth. Maize growing without fertiliser (B) and growing with 50 % compost enriched with urine + 50 % liquid urine (A) produced less biomass.**
Costs	- Investment costs: 2.7 Mio. € for the whole city (26'000 inhabitants ≈ 2'600 households) - Operating costs: 10'000 €/a for the whole city when maintenance is completed and the nutrients are used by the households

7.12 Constructed wetlands for different community levels in Nepal

Contact:	R.R. Shreshta Environment and Public health Organization (ENPHO) P.O. Box 4102 Kathmandu Nepal Or J. Mader Institute for Water Provision University of Agricultural Sciences Muthgasse 18 1190 Vienna Austria

References:	Shrestha, R. R., Haberl, R., Laber, J., Manandhar, R. & Mader, J. Application of constructed wetlands for wastewater treatment in Nepal. *Water Science and Technology* **44**, 381-386 (2001)

Systems applied:	- Two – staged subsurface flow constructed wetland - Constructed wetlands for treatment of greywater and septage

Level of application:	There are three CWs operating successfully in three different locations. These plants were constructed for different levels, ranging from plants for a household to plants for an entire hospital.

Project description:	One of the authors of the article with a group of Nepali professionals from the Environment and Public Health Organization (ENPHO) initiated the introduction of Constructed Wetlands (CW) in Nepal in 1995. With the technical collaboration of the Institute for Water Provision, University of Agricultural Sciences, Vienna, Austria, a pilot scale treatment plant in Dhulikhel Hospital was designed and constructed in 1997 as a first CW in Nepal. In 2001, there were three CWs operating successfully in three different locations in and around the valley of Kathmandu. **Dhulikel Hospital** A two-staged subsurface flow CW (horizontal flow followed by vertical flow bed) (see Figure 30) was built as the first full scale CW system in Nepal to treat Dhulikhel Hospital (45 beds) wastewater. The system operates without electricity, as water flows through the system due to gravity and the intermittent feeding of wastewater is done by a simple hydro-mechanical system. It has been in operation since July 1997, the total costs of the system is only 16 400 USD.

CW for Dhulikhel Hospital

Vertical flow bed just after completion

Vertical flow bed after reed growth

Design flow rate	: 20 m^3/day
Three chambered settlement tank	: 18 m^3
Horizontal flow bed	: 140 m^2 (7 × 20 m^2), filled with 60 cm of crushed broken gravel (pore volume 39%)
Vertical flow bed	: 121 m^2 (11 × 11 m^2), filled with 90 cm of clean sand $K_f = 10^{-3}$m/s
Vegetation	: Both beds planted with *Phargmites karka* (local reeds)

Figure 30: Pictures and characteristics of the system constructed for Dhulikhel Hospital

Plant for a household

Shortage of drinking water is a serious problem in Kathmandu. Present water demand in the valley is about 150 million litres per day (MLD), whereas production is only 90 MLD. In spite of this major problem, drinking water is being used for several non-drinking purposes such as flushing, washing, gardening, vehicle cleaning, etc. Realizing this problem, one of the authors has installed a greywater treatment system through CW at his own house to demonstrate water-recycling technology.

A household with seven members produces about 500 litres/day of greywater. It consists of wastewater from bathroom, shower, washing machine and wastewater from kitchen. For the separation of greywater from blackwater, separate plumbing has been installed. Thus separate greywater is collected into a settling tank for further treatment. The system consists of a two-chambered settling tank (500 L) as a pretreatment, a feed tank (200 L) and a vertical flow bed filled with coarse sand and planted with common reed (*Phragmites karka*) and *Canna sp*. as the main treatment unit.

The system does not need any electrical devices. Water is flushed hydro-mechanically into the bed 3 to 4 times a day. Finally the treated water is collected in an underground tank.

The collected water is used for flushing, gardening and cleaning. Thus, this house saves nearly 400 to 500 litres of water everyday. The system costs around US $ 430 for construction. The operating cost is negligible.

Experiences:

Dhulikhel Hospital

Table 29: Treatment efficiencies of the plant near Dhulikhel Hospital

Month	Q m^3/d	TSS IN mg/L	TSS OUT mg/L	NH_4-N IN mg/L	NH_4-N OUT mg/L	PO_4-P IN mg/L	PO_4-P OUT mg/L	BOD_5 IN mg/L	BOD_5 OUT mg/L	COD IN mg/L	COD OUT mg/L	E.coli IN col/ml	E.coli. OUT col/ml
nos. of reading	13	12	12	12	11	12	12	13	13	13	11	11	11
min	7	25.67	0.3	17	0.04	2.177	0.637	31.1	0	62.55	4.34	39000	3
Max	40	230	6.7	52.32	5.4	26	17.5	210	10	1048	40	8E+08	987
Avg.	19.6	82.92	2.283	33.296	1.604	7.908	4.223	109.9	3.287	324.5	20.2	1E+08	148
Median	10.7	41	1.8	19.167	0.04	2.177	0.67	40.93	4.167	79.2	18.2	1E+05	38
Std. Deviation	11.1	58.19	1.946	12.206	2.18	7.483	5.757	62.28	2.968	272.8	14.2	2E+08	307
Reduction Efficiency (%)			**97.25**		**95.183**		**46.6**		**97.01**		**93.8**		**99.9999**

IN – Wastewater water after primary treatment and inlet to CW; OUT – Final effluent of CW

Plant for Household

Table 30: Treatment efficiencies of a plant on household level

	TSS IN mg/L	TSS OUT mg/L	NH_4-N in mg/L	NH_4-N out mg/L	PO_4-P in mg/L	PO_4-P out mg/L	BOD_5 in mg/L	BO_5 out mg/L	COD in mg/L	COD out mg/L
nos. of reading	8	8	9	9	7	7	9	7	9	9
Minimum	52	0.5	3.66	0.02	0.79	0.78	100	0	177	6.8
Maximum	188	6	25.7	1.983	4.9	3.62	400	12	687	72
Average	97.9	2.6	13.3	0.5	3.1	2.0	200.1	5.2	411.4	29.1
Median	78.0	2.3	11.7	0.3	3.2	2.3	187.8	2.5	362.0	24.0
Std. Deviation	53.4	2.0	8.0	0.6	1.4	1.2	93.6	4.6	174.0	19.9
Elimination rate (%)		97		96		35		97		93

Costs

See above

8 Conclusions

8.1 Characteristics

The information available on the characteristics of greywater is exclusively derived from industrial countries, no values specific to developing countries could be found. But most of the information presented in this report is relevant for developing countries too, as the same processes influence the characteristics in developing and in developed countries.

There is an urgent need for more information about the characteristics of different types of greywater in order to be able to evaluate the potential for reuse and infiltration. It can also be concluded that the present knowledge about the characteristics of greywater (physical, chemical and biological constituents) is limited. Information about the presence and levels of most XOC's is totally missing.

The existing epidemiological database needs to be improved, too. Information on minimal infective doses, survival times, etc should be improved.
In addition, research should be carried out to possibly extend any microbial limits to include other microorganisms.

8.2 Treatment systems and their implementation

There is a broad choice of decentralised treatment systems for greywater. The systems mainly differ in terms of treatment efficiency (influencing the reuse option), dimension, price, durability and user-friendliness. The choice of a treatment system should thus be based on a careful evaluation of the local conditions, together with the beneficiaries of the system, taking into account aspects such as the legislation and the socio-economic environment as well.
Natural treatment systems such as constructed wetlands or pond systems are the most frequent systems presented in literature. Other systems such as trickling filters are also applied for decentralised greywater treatment, though less frequently.

Unfortunately, only few publications present treatment systems that suit the conditions in developing countries. Only little information is given about the treatment efficiencies and the pros and the cons of treatment systems. No long-term experience could be found in literature.
It is regrettable that no study focuses on the comparison of low-cost greywater treatment systems on household level. Such a study could enable an informed choice.

8.3 Guidelines

Two points are crucial for greywater guidelines:
- Firstly, if only limiting parameters for greywater characteristics are given or if in addition also the required treatment systems are described in the guidelines.
- Secondly, for the microbiological threshold values it is of importance which indicator organisms are chosen in the guidelines.

As mentioned above, there hardly exist any guidelines focusing specifically on greywater. The WHO is currently working on its own greywater guidelines. Some American States already have such guidelines. The gap of guidelines might be closed by the use of standards for reclaimed wastewater (if available), as long as greywater-specific guidelines are missing.

8.4 Case Studies

The identification of successful case studies in developing countries was very difficult. Information available on the internet is very scarce. Some interesting case studies were found, but often the information available is very general; data on design parameters, treatment efficiencies, etc. are rarely indicated. Most greywater treatment systems have never been monitored. In cases where detailed information would be available it could not be accessed in that short period of time, sometimes also due to change of the people in charge.

8.5 Résumé

The available data on decentralised greywater management in developed countries is very fragmentary. The situation is even worse when it comes to the situation for developing countries. It seems that long-term experiences are missing and ongoing surveys are rarely conducted in a scientific way, thus generating unreliable information.

Decentralised greywater management has an enormous potential in improving the sanitary situation in developing countries. The public health, environmental and economic improvements are convincing and it is astonishing that so little knowledge exists given those obvious advantages.

Given all those facts, further research is urgently needed.

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