Helophyte filters: Sense or Non-Sense?

A study on experiences with helophyte filters treating grey wastewater in the Netherlands

M.Sc. Thesis by Tiemen A. Nanninga

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Abstract

The use of helophyte filters for wastewater treatment is increasing in Western countries where decentralised wastewater treatment is being experimented with, but also in developing countries where the helophyte filters are implemented as part of development projects. In the latter context helophyte filters are often implemented like they would be in Western countries without being translocated to the different contexts, with all its consequences. This study focuses on the experiences with helophyte filters treating grey wastewater on neighbourhood scale at three locations in the Netherlands (Drielanden, Polderdrift and Lanxmeer). By analysing the characteristics of the influent, the design and implementation phases as well as the current functioning, performance and perceptions of the different stakeholders several pitfalls were identified. These apply for the Dutch situation, but have been linked to scenarios taken from the developing world in order to allow for better translocation of the wastewater treatment technology.

The composition of grey wastewater differs per country, sampling location and sampling period, indicating the dangers of assuming that wastewater characteristics of one location are similar to another. A proper design and construction is crucial for good functioning and performance, and a motivated organisation or association performing the operation and maintenance procedures is essential. A financial analysis shows that the costs of operating and maintaining three V-SSF helophyte filters in Lanxmeer, the Netherlands, is not more expensive than the use of the conventional sewage system. However, unexpected, sometimes large, costs can occur. Apart from the initial construction costs, which can be considerable, the operation and maintenance costs in combination with the need for proper conduction of operation and maintenance procedures and eventual renewal of the helophyte filter form the largest bottlenecks for development projects. The effluent from three V-SSF helophyte filters sampled during two weeks in the winter of 2011 was of similar or better quality than that of a nearby wastewater treatment plant. The inhabitants of the different neighbourhoods perceive the helophyte filters as a positive addition to their neighbourhood. Although occasionally noxious odours can be produced, this is not enough to complain about.

It is concluded that the sense of using helophyte filters for wastewater treatment in the Netherlands or developing countries is not as straightforward as one would hope. Although technologically speaking helophyte filters are suitable, the proper functioning and performance largely depends on critical financial and human demands as well, which can be very difficult to fulfil.

Further research on (Dutch) grey wastewater production and composition, the performance of helophyte filters in the summer and the experiences with, and functioning and performance of, helophyte filters in developing countries is recommended.

Key words: *grey wastewater, greywater, vertical flow subsurface helophyte filter, free water surface helophyte filter, removal efficiencies, performance, operation and maintenance costs, developing world, the Netherlands.*

Executive Summary

Helophyte filters are increasingly being implemented as a decentralised wastewater treatment technology in western countries. The perceptions that helophyte filters are solely for environmentalists and that they are uncomfortable in their use seems to have switched to the perception that helophyte filters are sustainable, ecological and cheap. The latter, with the perceptions that a helophyte filter is robust, biological and easy to operate and maintain are also reasons why helophyte filters are increasingly being implemented in developing countries. However, when this happens the technology is not translocated to the new setting and conditions, but rather implemented like they are in the western world, with all dire consequences.

This research focussed on learning from the experiences of using helophyte filters for wastewater treatment in the Netherlands, which has been happening for several decades. The lessons learned are then linked to developing countries. As a result, several critical pitfalls are identified, as well as possible measures against these.
It was decided to look at helophyte filters that treat wastewater on neighbourhood scale. The two main selection criteria were that the helophyte filter had to treat wastewater originating in households and that this had to happen at neighbourhood scale. Three Dutch cases (Drielanden in Groningen, Polderdrift in Arnhem and Lanxmeer in Culemborg) that adhered to these criteria were found. Although there have been other Dutch cases as well, these three were the only cases found to be functioning. At each of the cases the helophyte filters only treated the grey wastewater; the black wastewater was treated by the local wastewater treatment plant. The main reason for this was that people were hesitant to treat black wastewater within a neighbourhood due to the risks associated with it as well as the larger amount of space needed (and hence higher construction costs).

The research was based on the integrated reverse water chain concept, which is derived from field experiences as well as the reverse water chain and the settings approach. This concept allowed for an analysis of the wastewater treatment technology (in this case the helophyte filters), why this technology was implemented and the influence of the technology on the setting, and vice versa, in which it is placed.

In order to understand the use of helophyte filters for grey wastewater treatment in the Netherlands two literature studies were conducted. The first focussed on helophyte filters, their history and how pollutants are removed from wastewater. The second literature study focussed on the production and characteristics of grey wastewater. Next to these two literature studies multiple interviews were held with stakeholders at the three different case studies. Here those involved with the implementation, operation and maintenance and daily use were contacted. In addition, the influent and effluent of the three helophyte filters in Lanxmeer was sampled for a two-week period. This not only resulted in more data on grey wastewater characteristics and effluent of the helophyte filters in the winter, but also allowed for the calculation of removal efficiencies over two weeks.

The grey wastewater literature study has shown that the composition of grey wastewater can differ vastly per country, region and even case. There were large differences between grey wastewater produced in urban areas and rural areas, as well as grey wastewater produced in developing countries and western countries. Furthermore, one case in the Netherlands (Sneek) showed that grey wastewater characteristics can even differ between sampling periods. These findings show that not only is the time and type of sampling very influential on the grey wastewater characteristics found, but that (grey) wastewater characteristics found in one location can simply not be assumed to be similar at another location. The largest differences were found between the samples taken from rural and urban cases in developing countries.

The analyses of the three cases showed that in the initial phases a group of people, or even a single person, was the main motivator. This person or association managed to make other organisations, such as a municipality, Housing Corporation and potential inhabitants, enthusiastic to join the project and construct a neighbourhood with sustainable and ecological objectives. The construction of the helophyte filters was paid for by the municipality or Housing Corporation, who had larger budgets than the enthusiastic individuals or associations. In one case, Polderdrift, these costs were covered by donors who used it as an advertisement campaign. The construction of the helophyte filters at the other two cases was paid for by the municipality, who included these costs as part of the construction costs for the neighbourhood.

In Lanxmeer four different sewage systems have been constructed to transport the different wastewater streams. However, there have been several instances where faulty connections between the sewage systems have been made. This has happened within buildings where toilets or urinals (supposed to be connected to the black wastewater sewage system) have been connected to the grey wastewater system. This was also seen in the grey wastewater samples that were collected during the fieldwork; the grey wastewater from one of the sampling sites showed high NH_4^+ concentrations, indicating the probable

presence of urine. Although this has not resulted in dramatic consequences in Lanxmeer, it is not the first time in Dutch history that multiple piping systems in a neighbourhood have resulted in wrong connections with dire consequences (i.e. Leidsche Rijn).

Each helophyte filter needed tinkering during its initial use to ensure that the whole system worked properly. In all cases the pumps had to be programmed and in several instances pipes were later modified or installed. In Polderdrift the pumps were even relocated and the controls were reinstalled, resulting in high costs.

The performance of the operation and maintenance procedures was important to ensure proper functioning of the helophyte filter. In several instances these procedures proved more challenging or more expensive than initially thought. This was related to the type of helophyte filter (the mowing of macrophytes in FWS helophyte filters in Drielanden) and the extensive growth of weeds in V-SSF helophyte filters, which invade the helophyte filters from the surrounding banks. The latter resulted in Lanxmeer in much higher operation and maintenance costs than initially anticipated. In Polderdrift it has partly resulted in the deterioration of the overall state of the helophyte filter. The functioning of the helophyte filter in Polderdrift was also affected by the use of poor, or unsuitable, construction materials. The supposedly impermeable layer of clay underneath the helophyte filter broke and as a result it is thought that a large part of the grey wastewater percolates into the ground water instead of flowing into the effluent collection tank.

The operation and maintenance procedures in Drielanden and Lanxmeer are conducted by the municipality, who do it as part of their routine maintenance rounds. This has resulted in well maintained helophyte filters. On the other hand, in Polderdrift the inhabitants are responsible for a large part of the operation and maintenance procedures, which in theory works well, but in practice the motivation of inhabitants to actively being involved with these activities is declining.

A costs analysis of the helophyte filters at Lanxmeer showed that during 2010 the costs to operate and maintain the helophyte filters, save for renewing the helophyte filters in 20 years and maintaining the different sewage systems that collect and transport the different wastewater streams in the neighbourhood were similar to the costs of using the conventional sewage system in Culemborg. Of these annual costs, the largest part was used to maintain the different sewage systems in Lanxmeer. As there are four different sewage systems in Lanxmeer, these costs could be less in other cases. The costs related to the helophyte filter itself consisted of operational, maintenance and renewal costs. The smallest portion of the annual costs were spend on the operational costs, whereas the renewal costs were the largest (more than half) of these annual costs. Although the figures are different for Polderdrift, where a very rough financial analysis was done, the same trend was seen; the renewal costs formed the largest part of the budget.

The helophyte filters in Drielanden and Lanxmeer were found to be functioning properly. Not only was the water quality of the surface water body to which the effluent is discharged in Drielanden of high quality, but the macrophytes have resulted in a more diverse flora and fauna in the neighbourhood. The latter point also goes for Lanxmeer and Polderdrift, where more flowers and birds are noticed. The helophyte filter in Polderdrift does not function as well as it produces very little effluent. Nevertheless, it is said in all three cases that the inhabitants are positive about the helophyte filters because they increase the aesthetic value of the neighbourhood. An increase in flies and mosquitoes (and the feared introduction of malaria) has not been noticed or recorded. Neither have any illnesses related to the helophyte filters or grey wastewater been recorded, although at each case the helophyte filters are accessible by one way or another. A side effect of the helophyte filters is that several days per year, especially when the temperatures are high, a noxious odour is produced. The extent of this noxious odour differs, but it usually lasts one day at a time. These noxious odours have not led to the filing of any formal complaints and it is generally accepted as part of the wastewater treatment technology. However, if noxious odours are produced more than a couple of days per year it can result in a demolishment of the helophyte filter. This was the case in Drielanden, where initially a V-SSF helophyte filter was constructed as well. This helophyte filter did not function well, which resulted in a continuous production of noxious odours and a lot of complaints from the inhabitants.

The effluent of the helophyte filters in Drielanden and Lanxmeer is discharged to surface water bodies (the effluent of the helophyte filter in Polderdrift is collected in a tank and reused to flush the toilets). In both cases a permit to discharge effluent to the surface water bodies has been issued after construction was completed. The maximum allowable concentrations of several pollutants are stipulated in these permits and occasionally grab samples of the effluent are taken to check permit compliance. At Lanxmeer this is done annually by the Water Board Rivierenland, whereas in Drielanden this has been checked by the municipality of Groningen. However, the last time that this was done was in 2008, and before that in 1999. Overall the grab samples show that the effluent complies with the permit regulations. During two weeks in January and February 2011 composite samples of the influent and effluent were taken at the helophyte filters in Lanxmeer. These have shown that the composition of the effluent, in the winter, was well within the permit regulations. It also showed that the effluent of each helophyte filter was quite consistent in its composition, although there were differences between the effluents from different helophyte filters. The helophyte filters showed good removal efficiencies overall; for BOD_5 this was 97.7-99.9 per cent, for COD this was 89.1-96.7 per cent, for N-total this was 42.8-95.0 per cent, for NH_4^+ it ranged from 66.5 per cent to 99.7 per cent, for P-total it ranged from 69.4 per cent to 97.5 per cent, the TSS concentrations were lessened by 19.4-96.7 per cent and finally the helophyte filters showed a Log 2.5 to 5.2 reduction in *E.coli* concentrations. The effluent of the helophyte filters was similar to, or better than, the effluent of a nearby wastewater treatment plant, during the same time period.

As noted earlier, the users of the helophyte filters are generally positive about the helophyte filters. The same goes for those responsible for the helophyte filters and the operational and maintenance procedures. These people would recommend the use of helophyte filters for decentralised (grey) wastewater treatment in the Netherlands, although they did note that the use of a helophyte filter was not cheap by definition and that the operational and maintenance procedures did prove to be more work than anticipated. The helophyte filters were also recommended because of the increase in flora and fauna and aesthetic value.

It was though that the helophyte filters at Drielanden and Lanxmeer will continue to function like they do without much problems. If large maintenance requirements become relevant, the best action (invest or abandon) will be decided at that moment. However, in both cases the municipality seems motivated to continue using the helophyte filters for wastewater treatment. The helophyte filter at Polderdrift is, as noted earlier, in poor condition. At the moment the owner, Housing Corporation Portaal is deciding, in conjunction with the inhabitants of the neighbourhood, if they should keep things as they are (as there is no threat to the public health), renew the whole helophyte filter (which is thought to be very expensive) or demolish the helophyte filter and discharge the grey wastewater to the conventional sewage system. It is, at the moment of writing, not clear what will be done.
If the helophyte filter at Polderdrift is renewed, it will provide insight into how much this actually costs because there are as of yet no experiences with renewing helophyte filters in the Netherlands. At the same time, the demolishment of the current helophyte filter (with or without renewal) can be an opportunity to analyse the filtration sand and gravel to learn more about the binding of P, formation of biofilm and peat layers as well as the accumulation of solids.

The above findings have led to the identification of four pitfalls when implementing helophyte filters in developing countries.

The first pitfall is the construction costs of the helophyte filter and the piping systems needed to collect the wastewater and transport the effluent to a location where it is discharged or used. As shown in the financial analysis, these can be quite high (the renewal costs, based on the construction costs, were the highest annual costs related to a helophyte filter). These can be too high for a local household or community to finance.

The second pitfall is who will be responsible for the helophyte filter. If there are enough funds to construct a helophyte filter, which in developing countries generally comes from external donors, it is not a given fact that the organisation constructing the helophyte filter will also be responsible for the functioning and performance of the helophyte filter. Whether this is done by one person, a group of people or a large organisation, it is of critical importance that there is enough motivation and knowledge to ensure that the helophyte filter is properly controlled, operated, maintained and fixed if needed. The motivation could come forth from a sense of ownership and perceived need to treat the wastewater with the helophyte filter. If the treating of wastewater with a helophyte filter is not perceived as necessary (or, otherwise put, effluent of a certain quality is desired) by those responsible for the helophyte filter, it is doubtful if the helophyte filter will be monitored properly and action will be taken if required. The knowledge required could come in the form of clear manuals and trainings.

The third pitfall that is identified is the performance of the operational and maintenance procedures. If these procedures are not conducted properly and on time the state of the helophyte filter will eventually deteriorate and the helophyte filter will no longer meet the (initial) objectives. As these need to take place periodically enough motivation to perform these is needed. This motivation or enthusiasm is not the only requirement as there should also be enough knowledge, capacity and tools to perform the operation and maintenance procedures properly. This can be eased by tailoring the design of the helophyte filter to the specific situation (i.e. not using pumps if spare parts are hard to find, designing the helophyte filter in such a way that no large equipment is required for maintenance if this is not present or available).

The fourth pitfall is the high financial costs related to renewing the helophyte filter or (unexpected) large maintenance requirements, as well as the need to save for these costs. As the different cases analysed in this research have shown, unforeseen costs have occurred at all cases. This was usually related to the

tinkering required at the initial start of the helophyte filter to ensure proper functioning, but in other instances pumps had to be repositioned, additional piping systems had to be constructed and more maintenance was required. These were all unforeseen costs that required a substantial financial investment. The purposes of these costs have been critical for the proper functioning and performance of the helophyte filters, showing that they cannot be ignored. The need to save for maintenance or renewal costs that might occur in the (far) future can be difficult for a local community to perceive. This is related to their culture and can be less of an issue in other cultures. Furthermore, the need for a community to save for uncertain future costs when there are more important costs at that time will also be difficult, if not impossible, to accept. It might even seem completely absurd to do so.
Part of the initial 'tinkering' costs could be included in the construction budget, although this will increase these costs (see first pitfall). The money needed for large maintenance requirements or eventual renewal of the helophyte filter could be included with the general users' fees, although the person or organisation responsible for this will need to understand why it is being done. Furthermore, corruption is a danger here as eventually a relative large sum of money will be saved.

Another conclusion is that a helophyte filter can lend itself for other, perhaps income generating, activities. The clippings, for instance, can be pressed into bricks so that it becomes a slow-burning heat source, sold as ornamental flowers on a market (depending on the macrophytes used), or used as in a biogas installation to produce energy. Hence, by taking a wider approach the helophyte filter can not only treat wastewater, but also generate income.

Future scenarios, such as population growth, urban expansion and the introduction of new products in an area, such as flush toilets, chemicals, soaps and detergents can have an influence on the functioning and performance of a helophyte filter. Furthermore, if there are different piping systems, the installation of new sewage systems in an area or modifications made to a building can result in faulty connections between these different piping systems. This should be incorporated into the design of the helophyte filter by analysing different future scenarios, with their implications and the required performance of the helophyte filter, during the design phases. Although not all developments can be accounted for, this can result in the most optimal design for a specific location that allows for future expansions or adjustments.

When asking the question whether a helophyte filter as a wastewater treatment technology is sensible or non-sense, the answer shows the complexity of a helophyte filter. Technologically, a helophyte filter is capable of treating (grey) wastewater up to the condition where it can be discharged to a surface water body without increasing the threat to public health. However, there are also several other critical financial and social aspects that need to be addressed in order to let the helophyte filter function and perform properly. The critical points are related to the construction costs, the motivation to implement a helophyte filter, the need to adequately perform the operational and maintenance procedures and the need to save money for large (unexpected) maintenance costs and renewal costs. If these points are not adequately addressed beforehand, the implementation of a helophyte filter in a setting should not continue, as it will undoubtedly deteriorate. On the other hand, if these points are addressed properly, a helophyte filter is a suitable wastewater treatment technology.

The thesis ends with recommendations for more research on (Dutch) grey wastewater production and composition in order to optimise its treatability. In addition, it is recommended to conduct more research on the functioning and performance of helophyte filters in the summer, in order to learn more about the influence of warmer temperatures, as well as more research on the experiences with, and functioning and performance of, helophyte filters in developing countries in order to increase it applicability and success of implementation.

Preface

As part of my MSc in International Land and Water Management, with a specialisation in Irrigation and Water Engineering I performed this research. The result is an MSc thesis about the Dutch experiences with helophyte filters that treat (grey) wastewater. The lessons learned have been transposed to scenarios from developing countries.

The research performed for this thesis was undertaken in areas that I did find very interesting, but was not familiar with. Things such as wastewater treatment and the functioning of a helophyte filter were mentioned once or twice in courses or looked at in an internship or BSc thesis, but not as deep as in this thesis. Hence a lot of time was spent on learning new, basic principles of wastewater composition, its treatment and the functioning of a helophyte filter. I would like to thank all who have helped me learn these things and who have shown patience while I sometime plotted on.

Although I cannot thank all, there are a few people who I would especially like to thank:
My supervisors, Mr F. Huibers, Mr J. Blom and Mr J. van den Bulk not only allowed me to do the research, but also helped me a lot by guiding it and stimulated me to think critically about what I was doing.
The staff at the Irrigation and Water Engineering group and Water Technology department are also appreciated for their comments, answers, interest and good times.
I would also like to thank Mr E. Marsman from the Water Board Rivierenland for organising the funding that allowed for the analysis of the influent and effluent samples collected during the fieldwork. Although a lot of interviews were conducted by personal communication, email or phone several people have played a key role in gathering information about the different cases. For Drielanden Mr J. van Dijk and Mr H. Jager both provided a lot of information. Mr A. van Ruijven and Mr B. van de Ven assisted in gathering information on Polderdrift. In Lanxmeer Mr D. Hooijer was always tremendously helpful as well as Mr D. Boland and Mr L. Swinkels.

Last but not least, I would like to thank Loes for helping me with the fieldwork, encouraging me to go on with the research and writing and providing critical feedback.

Tiemen Nanninga, July 2011

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List of Acronyms

FWS	Free Water Surface
H-SSF	Horizontal Sub-Surface Flow
HLR	Hydraulic Loading Rate
HRT	Hydraulic Retention Time
KIWA	Previously Keuringsinstituut voor Waterleiding Artikelen (Institute for Approval of Water Products), but now has no meaning.
V-SSF	Vertical Sub-Surface Flow
RBTS	Reed Bed Treatment System
std	Standard Deviation
STOWA	Stichting Toegepast Onderzoek Waterbeheer (Foundation for Applied Research on Water Management)
WSP	Waste Stabilisation Pond

Chemical

Al, Al^{3+}	Aluminium
BOD	Biological Oxygen Demand
BOD_5	Biological Oxygen Demand after a 5 day period
Ca, Ca^{2+}	Calcium
$CaCO_3$	Calcium Carbonate, or chalk
COD	Chemical Oxygen Demand
Cu	Copper
E.coli	*Ecryptionate Coli*
Fe, Fe^{3+}	Iron
H^+	Hydron, Hydrogen with one cation
H_2SO_4	Sulphuric acid
$H_2PO_4^-$	Dihydrogen Phosphate ion
HPO_4^{2-}	Hydrogen Phosphate ion
K_a	Acid ionisation/dissociation constant ($10^{-9.25}$ or $5.62x10^{-10}$)
Mg	Manganese
N-total	Total Nitrogen concentrations
NH_3	Ammonia
NH_4^+	Ammonium
NO_2^-	Nitrite
NO_3^-	Nitrate
P-total	Total Phosphorus concentrations
pH	Measure of acidity; $pH=-Log(H^+)$
PO_4^{3-}	Phosphate
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen ($TKN=Organic\ N+NH_4^++NH_3$)
TSS	Total Suspended Solids[1]

Units

ºC	degrees Celsius
dS/m	Decisiemens per metre
cfu/100ml	Colony Forming Units per 100 millilitre of (waste) water.
FTU	Formazin Turbidity Unit (1 FTU = 1 NTU)
l/c/d	Litre per Capita per day
μm	Micrometre (1/1000th of a millimetre)
mg/l	Milligram per Litre
mmol/l	Millimole per litre (usually either Ca^{2+} or $CaCO_3$ for water hardness)
NTU	Nephelometric Turbidity Unit
p.e.	person equivalent

[1] Have been called Suspended Solids (SS) in the past. However, this is an old term and hence in this thesis the term TSS will be used. They are the same (Metcalf and Eddy, 2004).

Part A. Research Motivation and Set-up

1. Introduction

1.1. Introduction

This research focuses on helophyte filters treating grey wastewater in the Netherlands and the lessons learned that can be applied in Dutch cases or development projects. The main reason for focussing on helophyte filters that treat grey wastewater is that there are no large scale projects where domestic wastewater is treated by a helophyte filter in the Netherlands. Furthermore, the decision, design, implementation and functioning processes were assumed to be different, more bottom up, at these helophyte filters treating grey wastewater in a neighbourhood than with helophyte filters polishing surface water bodies, treating surface runoff or polishing the effluent of a wastewater treatment plant. Helophyte filters with the latter three objectives are usually implemented by Water Boards or water treatment facilities. As a result the implementation of these helophyte filters is more top-down and society can hardly influence the earlier mentioned processes, resulting in different paradigms and processes.

This research will start with a general explanation of helophyte filters and how they remove different pollutants from wastewater. A literature study on grey wastewater production in Dutch households, as well as characteristics of Dutch, European and international grey wastewater is also conducted. Next, three helophyte filters located in the Netherlands will be described in terms of History, Technology, Actors, Operation and Maintenance, Costs and Financing, Functioning, Performance and Perception, Future and Recommendations. This was done through literature, analysing existing data analysis and interviews. At one case the influent and effluent was sampled to calculate the removal efficiencies during two weeks in the winter.
The different studies come together in the analysis, which lead to the conclusions and recommendations. In these three chapters the pitfalls for implementing helophyte filters, with actions to take against them, become clear. The pitfalls identified will be linked to scenarios taken from the developing world, based on personal experiences, in the analysis.

1.2. Background

Helophyte filters are increasingly implemented for wastewater treatment in the Netherlands and abroad. Although helophyte filters were specifically developed to treat wastewater in the 1950's and 1960's it was not until the 1980's when more knowledge about the technology was gained. The rate of implementation has rapidly increased since then (Vymazal *et al*., 2006; Vymazal and Kröpfelová, 2008). An example of this is North America, where there were 300 helophyte filters in 1990. In 2008 this had increased to over 8000. (Vymazal and Kröpfelová, 2008). In Europe this number currently exceeds more than 50,000 with the majority in Germany (Vymazal *et al*., 2006).

Although the reasons for implementing new helophyte filters are often very clear, the experiences of using these helophyte filters are hardly ever heard of afterwards. As western countries are implementing helophyte filters for wastewater treatment in their own countries, it is assumed that these can also be implemented in other countries for similar purposes. Indeed, it has been noticed that donors use technologies from their home countries in development programmes, without questioning whether this technology is suitable for the developing country (Denny, 1997; Kivaisi, 2001). There is no adaption of the technology, or translocation, towards the situations present in the developing country. This seemingly unquestioned positivism towards, as well as the lack of translocation of, the helophyte filter is questioned in this research.

This research focuses on the Dutch experiences with helophyte filter use for wastewater treatment. These experiences are mapped out, which should lead to an identification of the pitfalls present. These experiences and pitfalls will then be analysed in the light of scenarios from developing countries. The overall research will hence not only lead to a bundling of information on the use of helophyte filters for wastewater treatment in the Netherlands, but also to recommendations for the use of helophyte filters in the Netherlands and in developing countries.

In order to investigate how helophyte filters function and perform when used at a larger scale this research is performed at neighbourhood level. In the Netherlands only grey wastewater (wastewater coming sources in a household such as shower, laundry, sinks and kitchen, but not from the toilets or urinals) is treated by helophyte filters at this scale. Reason for this is that there is a general hesitation towards treating wastewater containing faeces in a public space. Furthermore, there is no immediate need to treat these wastewaters in a public space as there is an extensive sewage system (104,300 km long) already constructed in the Netherlands. This sewage system reaches 99.8 per cent of the population (Stichting RIONED, 2010) and hence provided a good opportunity to discharge black wastewater to.

1.2.1. New Sanitation

Domestic wastewater production, per person, is lessening in the Netherlands as less water is consumed per person (see section 6.1). Nevertheless, this does not mean that the Dutch wastewater treatment sector does not have any challenges left. The current, conventional, wastewater treatment system in the Netherlands has always been a centralised, environment-independent, bulk-treating system with end-of-pipe-solutions and minimal involvement of society (Lier and Lettinga, 1999; Palsma and Swart, 2009). This system has a huge capital value (unknown) as well as high annual maintenance costs (€1.07 billion, excl. taxes).

Intensive and prolonged rainfall in combination with an increase in paved surface area where the rainwater cannot infiltrate result in larger peak flows that need to be diverted away. This can result in local flooding. If this water is led into the sewage system it can result in an overflow of wastewater from the sewage system to surface water bodies. The rainwater that is collected by the sewage system will also need to be treated by the wastewater treatment plants. Ninety-two per cent of the Dutch municipalities are already taking measures against this by installing separate sewage systems for rainwater as well as storage basins and infiltration areas (called wadi's) (Stichting RIONED, 2010).

The high costs related to the current sewage system as well as the measures that the municipalities are taking to discharge rainwater separately have become the basis for a new concept called New Sanitation. There are three main domestic wastewater streams identified within the New Sanitation concept: Brown wastewater (wastewater containing faeces, originating in the toilet), yellow wastewater (wastewater containing urine, originating in the toilet or urinal) and grey wastewater. Blue water (rainwater) is also considered separate, but not as a domestic wastewater stream. If urine is not collected separately in the toilet the combined brown and yellow wastewater streams are called black wastewater.

Black (or brown and yellow) wastewater is the most polluted wastewater stream coming from a household. As STOWA had limited resources for research, it advised in 2006 that these resources should be used to gather knowledge on the treatment of black (or brown and yellow) wastewater as well as the reuse or discharge of the retrieved nutrients and produced effluent (Palsma *et al*., 2006). Although the collection, transport and treatment of grey wastewater was considered essential for the whole picture it was regarded as not important enough for initial research as the concentrations of pollutants are lower than those in black wastewater (see section 6.2). This is supported by a literature review that shows the relative small amount of Dutch literature on grey wastewater collection, treatment and effluent use (Blom *et al.*, 2010).

There are several technologies with which grey wastewater can be treated in a decentralised manner (e.g. membrane filtration, microbial reactor (MBR), rotating biological contractor, sand filter, biofilm reactor, Upflow Anaerobic Sludge Blanket (UASB) reactor and helophyte filter). The helophyte filter is currently the only technology used to treat grey wastewater on neighbourhood scale in the Netherlands.

1.2.2. Helophyte Filters

During the past two decades helophyte filters have seen an increase in implementation in the Netherlands and abroad. This can partly be ascribed to changes in Dutch legislation resulting in mandatory treatment of domestic wastewater produced by individual households and farms not connected to the conventional sewage system before discarding the effluent to surface water bodies (this was not the case in the Netherlands before 2005). Furthermore, due to their biological mechanisms helophyte filters are perceived to be cheap, ecological, sustainable, innovative, easy to maintain and robust and are hence applied in ecological projects and developing countries.

Helophyte filters have not always been perceived as ecological, sustainable, innovative and robust (Vymazal and Kröpfelová, 2008). In the Netherlands they have been associated with environmentalists and were hence perceived as rough, poorly functioning, a source of pests and not comfortable in use. Although these opinions still persist (Palsma *et al*., 2006) they have lessened over time. This could be explained by the increase in implementation, the existence of several professional companies constructing helophyte filters (e.g. BrinkVos Water, Ecofyt) and the Dutch quality label attributed to the construction of a specific type of helophyte filter (KIWA label BRL-K10005, see section 5.3.1).

It is striking, however, that it seems that the early attributions made to helophyte filters (rough, smelly, source of pests, malfunctioning) have not been based on concrete studies. Instead, failed cases such as de Biezenlanden[2], although they have not been studied in depth, have been used to motivate the

[2] The neighbourhood Biezenlanden (Currently named Klein Wantij, located on the Makoré street in the quarter Stadspolders) in Dordrecht (NL) used four V-SSF helophyte filters with a total surface area of 456 m^2 to treat the grey wastewater before using the effluent to flush toilets. The helophyte filter was designed by Ecofyt, who in turn hired HelkantPlant to construct it (Verhoeven, 2010). The municipality was responsible for the 50 houses that were constructed here as well as the helophyte filters that were finished in 2000 (Dien, 2009; Verhoeven, 2010). Unfortunately, due to the poor construction materials used the

statements made. The positive attributions made to helophyte filters also seem not to be based on in-depth studies but rather on positive cases or assumptions.

Helophyte filters seem to have a lot of (different) perceptions surrounding them. Although they are enthusiastically implemented in the Netherlands and abroad and more research is being done on them, there is still little (bundled) knowledge and concrete proof for the implementation or rejection of helophyte filters.

1.2.3. Implementation in Society

Helophyte filters have four general uses in the Netherlands, namely to treat surface runoff from roads, polish surface water bodies, polish effluent from wastewater treatment plants and treat grey wastewater in suburbs (Bak *et al.*, no date).
In all cases pollutants are removed from water, although the measure at which this is done differs. Either way, if helophyte filters unknowingly do not function as expected the environment will be polluted. Not only that, but society will eventually be exposed to the polluted water, resulting in a potential threat to the public health of that area. Hence helophyte filters can form a direct threat to public health if they are not constructed, used or maintained properly.

1.2.4. Personal Motivation

During my internship and BSc thesis research I got familiar with helophyte filters. At the same time, the discovery that there are still a lot of unknowns and that knowledge was scattered was made. Recommendations for helophyte filter implementation seemed to be based on assumptions and there was no overview about the actual construction and operation and maintenance costs. An MSc thesis with these aspects in mind seemed a logical next step.

1.3. Problem Statement

1. In the New Sanitation concept the different wastewater streams are collected, transported and treated separately. Hence each stream becomes relevant. The little knowledge about the relative large and diluted grey wastewater stream in the Netherlands influences its treatability as well as the feasibility of decentralised sanitation projects.

2. Helophyte filters have been surrounded by conflicting perceptions. In addition, general knowledge about specific operational and maintenance requirements as well as all costs related to helophyte filters is either scattered or absent. Nevertheless, they are implemented all over the world to treat or polish polluted water. The malfunctioning of a helophyte filter in these cases could result in a threat to the public health as well as a waste of financial means and effort.

1.4. Research Objectives

The aims of this research are to (1) bundle knowledge on grey wastewater characteristics; (2) identify paradigms present during design, implementation and use of helophyte filters treating grey wastewater in the Netherlands and (3) determine the performance of helophyte filters during two winter-weeks in the Netherlands. The pitfalls that are then identified will be analysed and the conclusions and recommendations will then (4) be ‘exported’ to scenarios from developing countries.

1.4.1. Societal Relevance

A Dutch household produces an average 120 litres of wastewater per capita per day. Of this volume, an approximate 34 litres is black wastewater, and the remaining 86 litres grey (section 6.1; Foekema and Thiel, 2011; Mels *et al*., 2005a). There are several benefits of keeping these two wastewater streams separate and treating grey wastewater on-site. Not only are treatment costs lowered as there is a smaller volume of wastewater heavily polluted (yellow, brown or black wastewater), but it is possible to recover nutrients such as struvite and energy in the form of biogas from these wastewater streams, although this is currently not always profitable. In addition, the sewage system will need to handle just the black wastewater stream if this is not treated locally as well, and surface runoff if the latter is not diverted to nearby surface water bodies. The treated grey wastewater can be discharged to surface water bodies, used for irrigation and/or for replenishing groundwater where no drinking water is extracted.

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wooden-frame houses were demolished in November 2003 and the helophyte filter was hardly ever used (Municipality of Dordrecht, 2003; Verhoeven, 2010; VROM, 2003). The helophyte filter was removed as well to make place for the new neighbourhood, Klein Wantij.

1.4.2. Scientific Objectives

Due to past negative experiences with treated grey wastewater use[3] and the low concentrations of pollutants the onsite treatment of grey wastewater has been questioned. This research aims to give a brief overview of general research conducted on the subject, as well as generate new knowledge on the functioning of three helophyte filters used for grey wastewater treatment in the Netherlands. Thus the research is partly descriptive (the literature reviews and case descriptions) and partly exploratory (analysis of the functioning of helophyte filters and generation of more data on grey wastewater).

1.4.3. Personal Objectives

During my internship and BSc thesis research I got familiar with helophyte filters and as a result also with the lack of knowledge that seemed to exist. As an International Land and Water Management student I have learned a lot about irrigation and water management in developing countries. Having grown up in Malawi and Kenya I hence have vast experience with cases abroad but little knowledge about the Dutch water sector. This MSc thesis provided the opportunity to not only learn more about helophyte filters, but also about wastewater and its treatment in the Netherlands. In addition the interviews, correspondence with different companies and experts also increased my network of contacts. Lastly, this MSc thesis research gave more experience in conducting research. Preparing for measurements in the field, doing interviews, conducting extensive literature research and finally writing it all down were just some of the experiences that helped form my ideas about a future career.

[3] A famous Dutch example is Leidsche Rijn, Utrecht (NL). Here treated grey wastewater was provided as potable water and the potable water provided by the drinking water company was used to do the laundry instead of the treated grey wastewater. This sparked a political debate and as a result the reuse of treated grey wastewater in households on neighbourhood scale is not longer allowed (Geel, 2003).

2. Definitions and Theory

In the two following sections the definitions of certain words used in this thesis are explained and the theories that formed the basis of the research are explained. By using these two different theories, the Reverse Water Chain and Settings Approach, one theory focussed on the treatment of wastewater, whereas the second theory focussed on the setting in which this wastewater treatment was placed. The data gathered during the research allowed for a change in the Reverse Water Chain theory and hence the two theories are combined with these changes in the conclusions of this thesis (see section 11.5).

2.1. Definitions

Wastewater is the water or liquid that carries wastes from households, industries, institutions, hospitals and agriculture. It might be combined with groundwater, surface water or storm water flows present (Martijn and Huibers, 2001). **Domestic wastewater**, which is wastewater coming from households, schools or offices, can be divided into three different groups. **Black wastewater** is the wastewater that is carrying, or contaminated with, human and/or animal excreta (NWP, 2006). This wastewater stream is generally associated with high pollutant concentrations (biological and chemical). Pathogenic concentrations are also higher and it hence forms a greater threat to public health (Asano and Levine, 1996; Martijn and Huibers, 2001). Within black wastewater two other streams can be distinguished. The **brown wastewater** stream contains only faecal matter and toilet paper, whereas the **yellow wastewater** stream consists of urine. These streams can be collected separately in specific toilets. The wastewater not included in the black wastewater stream is called **grey wastewater.** Grey wastewater originates in kitchen, showers, baths, sinks and laundry facilities in a building (Elmitwalli and Otterpohl, 2007; Eriksson *et al*., 2002; Gross *et al*., 2005; Hernández Leal *et al*., 2007; Jefferson *et al*., 1999). Each of these sources has its own specific pollutants and in varying concentrations. It is more diluted than black wastewater and contains the major fraction of heavy metals but a minor proportion of pollutants (or nutrients, depending on the use of the treated wastewater) present in domestic wastewater (Vinnerås, 2002). **Municipal wastewater** is the wastewater produced by a municipality. It consists of domestic wastewater as well as industrial wastewater (if there is a permit to discharge the industrial wastewater to the sewage system) and in some cases rainwater.

Helophyte filters, also known as planted soil filters (NWP, 2006), reed beds, constructed reed bed systems (Dallas *et al*., 2004; Green and Upton, 1995), or constructed wetlands (Dallas *et al*., 2004; Masi and Martinuzzi, 2006), are water tight basins in which macrophytes grow. Depending on the type of helophyte filter the macrophyte is submerged, floating or emerging. The macrophytes are planted in the sand or clay layer in the helophyte filter (Masi and Martinuzzi, 2006; NWP, 2006).
Helophyte filters can be distinguished into two different categories namely surface flow (free water surface or FWS) and subsurface flow (SSF or reed-bed treatment system, RBTS). A FWS helophyte filter is a basin in which the wastewater flows horizontally over the bottom of the basin, in which the macrophytes are planted. With an SSF helophyte filter the wastewater flows through the medium with which the basin is filled. This medium is usually sand. Two different directions of flow can be distinguished, which are vertical flow (V-SSF) where the wastewater is distributed on top of the basin and is collected by drainage pipes on the bottom of the basin, and horizontal flow (H-SSF). In the latter the wastewater is distributed on one side of the helophyte filter and flows horizontally through the medium to the other side, where it is collected (Masi and Martinuzzi, 2006). For more details see section 5.2.

Decentralisation is defined by the Oxford University Press (2011a) as the movement of something, like a department, away from the single administrative centre to other locations. In other words decentralisation involves the distribution of one certain thing from one location to several locations. Hence **decentralised wastewater treatment** is the treatment of relative small amounts of wastewater in multiple locations. These locations can be the size of a single household or a whole neighbourhood. In this perspective a decentralised activity (e.g. wastewater treatment plant treating wastewater from a municipality being split up into several smaller wastewater treatment plants treating wastewater from a neighbourhood) can in itself be decentralised again (e.g. the previously mentioned neighbourhood-scale wastewater treatment plant being split up in wastewater treatment plants for individual houses).

A **setting** is a place and social context where people engage in daily activities in which environmental, organizational and personal factors interact. Hence their needs and capacities are included in the analysis and there is room for unpredictability's and changing of context. As a result a setting is by definition complex and non-linear. A setting is either closed (organization) or open-ended (Dooris, 2007; 2009).

The understanding, opinions, or ideas created by information acquirement processes (especially senses) of the public is called **public perception**. It is how society regards an issue. The public perception is influenced by the perceptions of the individuals in society and in turn influences the perceptions, or opinions, of these individuals (Averill, 1958; Kim *et al*., 2007; Oxford University Press, 2011b).

Stakeholders are actors who have an influence on, and are influenced by, the implementation of a concept, idea or project. These can be the people influenced by the outcomes, or people responsible for the implementation of the concepts, ideas and/or programmes. Stakeholder involvement, or the involvement of these stakeholders, is critical to the success of a project and means that participation should have a role at each step. Knowledge of culture, traditions and local wishes are all key aspects (Vink *et al*., 2008).

Sustainability is the type of use of resources (consisting of the (local) environment, social system and economy), orientation of development and institutional change so that the current needs and aspirations are met, but future generations are still guaranteed access to these as well (WCED-OCF, 1987).

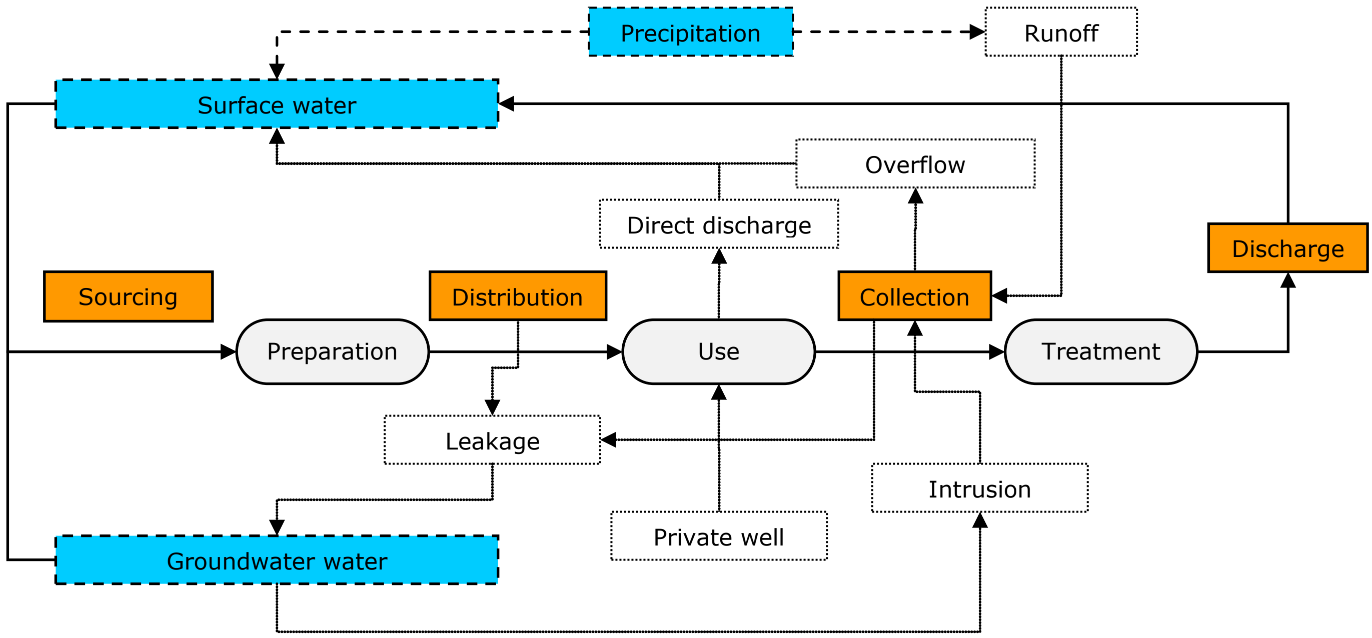
2.2. *Theory*

2.2.1. Urban Water Chain

The urban water chain is a concept in which a water flow is followed from the initial sourcing and treatment, via the distribution to the different users, from where it goes to wastewater collection, treatment and discharge of the effluent. Although there are interactions with the surrounding water system(s) and it is a subsystem of the larger water cycle, the other water systems such as surface water, groundwater and the relations with the soil and atmosphere are not included (Bots, 2008; Krozer *et al*., 2010; VROM *et al*., 2003). The urban water chain is schematically represented in Figure 1. The different departments, with their domains, that are involved in the Dutch water chain are also presented here. The water is usually supplied at a level of high quality and is used for domestic or industrial purposes. It should be noted that in Figure 1 the use of the effluent is not clearly depicted. The assumption here is that in the Netherlands treated wastewater is discharged to surface water bodies from where it is sourced and prepared for use again.

2.2.2. Reverse Water Chain

Huibers and Lier (2005) have added a step to the urban water chain earlier depicted (or formulated differently, have visualised the missing step in Figure 1). This step consists of using the wastewater after it is discharged, whether treated or untreated. This use can be irrigation in the agricultural sector, groundwater replenishment, industrial uses or domestic purposes before it is discharged (Figure 2). An important note to make is that the required quality of the treated wastewater is flexible and negotiable and depends on its typical use (Lier and Huibers, 2010).



Drinking Water Company	Household/Industry	Municipality	Water Board
Provincial Government			
National Government			

Figure 1. Systematic representation of the water chain within the larger water system (adapted from Bots, 2008; VROM *et al*., 2003)

The general presumption in this concept is that the urban water chain is followed from left to right, or from source to treated wastewater. Rather, if the water chain is read from right to left, or from treated wastewater through the sewerage system to the consumer, new insights into wastewater treatment are created. The quantitative and qualitative water quality requirements of the final users thus determine to what extent the wastewater needs to be treated. Furthermore, the quality of the wastewater produced will determine to what extent the pollutants need to be removed. As a consequence the user, or purpose, of the wastewater determines the quality to which this wastewater is increased instead of government legislation (Lier and Huibers, 2010). This does not mean that government legislation is put out of play as guidelines specific to a certain use still need to be ensured, but rather that the government legislation for wastewater discharge is not followed blindly. The reverse water chain also implies that the stakeholders need to intensify the communication amongst themselves with the result that new interventions and innovations might be identified, as well as a sharing of the costs as more stakeholders will benefit due to the access to available resources and benefits.

By treating the wastewater to a quality which is sufficient for a certain low-quality-demanding-use costs could be saved as certain treatment steps will not be necessary. Within the reverse water chain concept the effluent of the treatment system is used, and the water chain becomes a cycle with a feedback loop determined by the reverse water chain thinking.

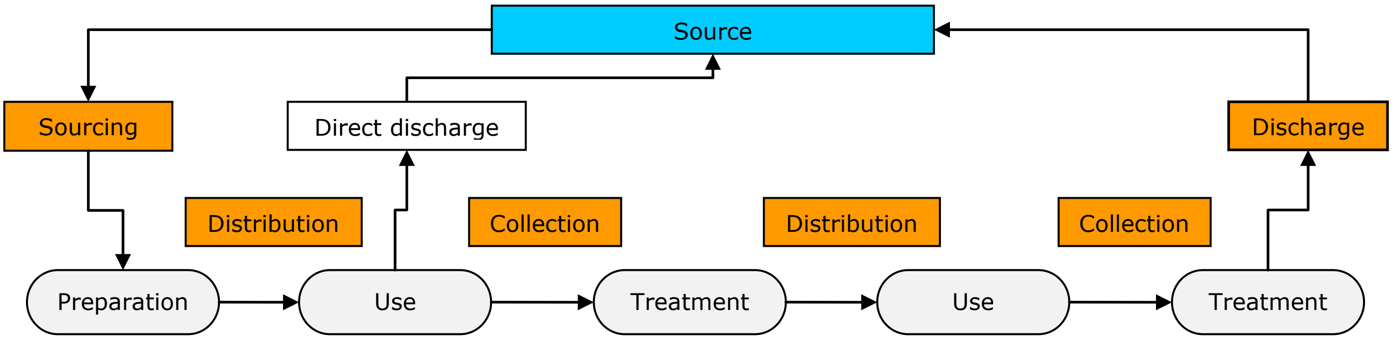


Figure 2. Systematic representation of the water chain with an additional step as described by Huibers and Lier (2005)

2.2.3. Settings Approach

The settings approach is a framework that originates in the public health arena. It emerged after the WHO stated that *"Health is created and lived by people within the settings of their everyday life; where they learn, work, play and love"* (WHO, 1986). The settings approach is known for the diversity in actions that it allows. Participation, equity and partnership are three key values that the approach is based upon (Dooris, 2009). There are three interconnected dimensions in the settings approach: an ecological model, which consists of understanding the setting; a systems perspective, which allows for change; and a whole-system development and change, resulting in development (Dooris, 2007; 2009).

Within the ecological model the focus is shifted from one single issue, problem, risk factor or linear approach to a more holistic vision of the issue in which complex interactions within and between persons, society, organisations and the environment are seen within the context and places that people live their lives (Dooris, 2009).
Within the settings approach framework settings are viewed as complex, dynamic systems. These systems have inputs, outputs and throughputs. The individual components of the system are connected and form a synergy. There is an interaction between the components of one system and another, which means that systems are always open and linked to the wider environment (Dooris, 2009).
The last dimension, the whole-system development and change, takes the entire setting into account when introducing, managing and sustaining change. This change can be triggered from inside (bottom-up) or outside (top-down) the system. Local values and norms, ways of thinking and interrelationships play important roles in these processes. The aim is that the change is incorporated into the way of life that exists in the system and improves its overall well-being and that, though the interrelationships, it will be exported to other system in a natural way (Dooris, 2009).

The settings approach was developed in the western world, as is previously described. However, the three key values of the approach allow for an application in developing countries as well because the new setting, culture, values, norms and way of thinking of the location are taken into account before the intervention is started. As a result the intervention is translocated to the new location without changing the original principles of that intervention (Dooris and Hunter, 2007; Dooris, 2009). Long term goals and short term achievement are balanced, top-down and bottom-up movements are combined and the public and private sectors are both involved to result in an overall success (Dooris, 2009).

3. Research Questions

3.1. Main Research Questions

- *How do helophyte filters treating grey wastewater in the Netherlands currently function and perform in relation to the design criteria, and what common operational pitfalls, in implementation and use, can be identified?*
- *What are the implications of these (operational) pitfalls and how can these be avoided?*
- *How do these identified pitfalls relate to Dutch and developing-world scenarios?*

3.2. Sub-Research Questions

The sub-research questions focus on gathering background information about grey wastewater and the different cases in order to answer the main research questions.

- *What are main uses of helophyte filters in the Netherlands and developing countries?*

- *What are Dutch and international grey wastewater characteristics found in literature?*
- *What are the grey wastewater characteristics at the three selected sites in the Netherlands?*

- *How were the three selected helophyte filters in the Netherlands designed and realised?*
  - *What was the motivation for implementing a helophyte filter?*
  - *What were the design objectives?*
  - *Who were the different stakeholders?*
  - *What were the construction costs and who paid these?*
  - *Who was responsible for the design and construction?*
  - *What were major un-anticipated issues that came up during the construction phase?*

- *How have these filters been functioning since?*
  - *How are the design objectives met?*
  - *What are the treatment efficiencies of the selected helophyte filters?*
  - *How do stakeholders perceive the technology?*
  - *What are major un-anticipated issues that have come up since the technology was constructed?*
  - *How is the future perceived?*

- *What pitfalls can be identified?*

- *How do the identified pitfalls relate to scenarios taken from the developing world?*

- *What are measures that can be taken to avoid the identified pitfalls, in Dutch cases as well as in international cases?*

- *What is the role that helophyte filter could take within the New Sanitation concept?*

4. Research Methodology

4.1. Research Methods

The research consisted of performing two literature studies (Part B. Literature Studies), conducting interviews, and collecting samples at one of the Dutch cases (Part C. Case Descriptions). These two parts will then come together in the analysis, conclusions and recommendations (Part D. Analysis, Conclusions, Reflection and Recommendations).

The sites that were selected for measurements and interviews are Drielanden, (Groningen), Polderdrift (Arnhem), and Lanxmeer (Culemborg). The criteria for selecting these sites were that the grey wastewater produced in the neighbourhood had to be treated by a helophyte filter. These three sites were, after extensive research, the only sites in the Netherlands where helophyte filters treat grey wastewater on neighbourhood scale.

Two literature studies were conducted: One on helophyte filters, their history and how they function and the second on Dutch and international grey wastewater characteristics. Literature was retrieved from the internet using scientific search engines such as Scopus and ScienceDirect. Literature was also collected from the libraries at Wageningen UR, Tauw bv, and personal documentations. This literature was then organised according to the different subjects. Information collected that related to a specific case was stored with other information and literature related to this case,

Interviews were conducted with people who were involved with the construction of the helophyte filter, who are responsible for the helophyte filter and whose grey wastewater is treated by the helophyte filter. Interviews were mainly done by going to their houses and/or offices. If this was not possible or if it was not efficient to do this the interview would be conducted by telephone and/or email.

The fieldwork consisted of a two-week period (24 January 2011 till 4 February 2011). Water samples were collected and analysed in the field for dissolved oxygen, temperature and pH. The water samples were then delivered to the laboratory of Water Board Rivierenland who analysed the samples for BOD_5, COD, TKN, NO_2^-, NO_3^-, NH_4^+, P-Total, TSS and Pathogens (*E.coli*).[4]

The information gathered during the literature studies, interviews and fieldwork was brought together in the analyses. In this analysis a comparison with Dutch, European and other international cases was made.

4.2. Strategy of Data Collection, Management and Analyses

As explained earlier, the sources collected during the literature studies were stored by subject. This was done digitally. Certain documents could only be retrieved in hard-copy version. These were organised and stored in several binders in the same way as the digital documents.

The first interviews were open-ended. Although there was a list (See Appendix 1) with points that needed to be answered this was done in the form of an informal conversation to retrieve as much information as possible and at the same time create an environment in which the interviewee would feel comfortable expressing negative feelings or frustrations as well. The second round of interviews was done after more in-depth research on each case was conducted. As each interviewee also gave a list of further possible contact persons, these were also analysed for their suitability. The interviews in the second round were usually more specific as in these cases specific information was required. In the final round very specific information was needed and hence people with this specific knowledge were sought.

The collection of wastewater samples is described in detail in the next section.

All data collected was stored digitally per case, such sub-folders for interviews, measurement data, pictures or literature. The literature from the case studies was stored per subject in a folder called literature. A back-up of all data was made at least once every two weeks.

The data collected during fieldwork, as well as the data received from the laboratory was also categorised per location. Each parameter was then analysed statistically with SPSS (version 12.0) to produce the Mean, Minimum, Maximum and Standard Deviation values. These were used in the analysis as they provided a good indication of the variance in the collected data. If this variance was relatively small the mean values, per location and per parameter, could be used as a representative value for the influent or effluent.

[4] N-Total was calculated by adding TKN, NO_2^- and NO_3^-.

4.3. Sampling

The oldest case of this thesis is Polderdrift, which was constructed in 1993 to treat grey wastewater at neighbourhood level. The youngest case, Lanxmeer, was constructed in 2003 and is treating grey wastewater for 8 years. This thesis research provides an excellent opportunity to assess how well the grey wastewater is treated after approximately one decade, how these compare to other known cases and if the requirements that led to the design have been met. By comparing the initial design requirements with the current situation lessons can be learned for future implementation of helophyte filters treating grey wastewater. Furthermore, experiences with the helophyte filters designed for this specific purpose can be analysed. This can help in the decision making about the future of these specific helophyte filters as well as helophyte filters now being constructed (or designed).

This field study has two objectives:

- *to gain more insight in the functioning of the helophyte filters treating grey wastewater in Lanxmeer, Culemborg, during two weeks in the winter*[5]*, and*
- *to compare measured grey wastewater characteristics with those found in literature as well as the design criteria.*

4.3.1. Parameters

Both influent and effluent characteristics are analysed. Each analysis consisted of the following parameters: BOD_5, COD, TKN, NO_3^-, NO_2^-, NH_4^+, P-Total, TSS and Pathogens (*E.coli*). Dissolved Oxygen, Temperature and pH were measured in the field.

These are general parameters found in literature and give a good overall impression of the characteristic of the influent and effluent. Furthermore, these are the general parameters that are also used by the Dutch Water Boards when they analyse the influent and effluent of their wastewater treatment plants. A number of these parameters, with threshold concentrations, are also used by the Water Boards when they issue permits to industries, companies, farms, households or municipalities that want to discharge (treated) wastewater to surface water bodies.

More in-depth parameters, such as micro pollutants and heavy metals were not in the scope of this study as this study is of the explorative and descriptive kind. More in-depth analyses were also not possible due to the lack of financial means, measurement devices and analyses.

4.3.2. Site selection

The Water Boards in whose area the different cases are located have been contacted about providing the analyses for this study. Unfortunately, Water Board Noorderzijlvest (for the Drielanden case) did not see the necessity to cooperate with this study and hence the influent and effluent of the helophyte filter in Drielanden could not be analysed. Water Board Rivierenland did agree to analyse 36 samples. Thus the helophyte filters in their administration area were analysed (Polderdrift and Lanxmeer). As the helophyte filter in Polderdrift is not functioning properly (none or very little effluent) it was left out of this study. Therefore the three helophyte filters in Lanxmeer were the only ones where the influent and effluent was sampled and analysed in this study.

Figure 3. Location of influent (dark grey) and effluent (blue) sampling points in Lanxmeer

The grey wastewater in Lanxmeer, Culemborg, is treated with three helophyte filters (named *Station*, *School* and *Unie*, after their locations). The effluent of these helophyte filters is discharged in surface water bodies. Each helophyte filter treats the grey wastewater of a different part of the neighbourhood. This grey wastewater is collected in a collection tank, in which there is a pump. When the water level in this tank reaches a certain height the pump switches on and pumps the grey wastewater to the helophyte filter. This way the influent is fed in an intermittent flow to the helophyte filters (Hooijer, 2010a).

[5] As the climate has an influence on the functioning and performance of the helophyte filter, the results of this study only describe the functioning and performance of the helophyte filters in the winter as the samples were collected in this season.

The effluent of the *Station* helophyte filter flows into another tank in which a pump pumps the water into a stream when the tank is full. The effluent of the other two helophyte filters flows into other surface water bodies by gravity.

As all grey wastewater is collected in collection tanks, these were the location where the influent samples were collected (see Figure 3 for the different location as well). Effluent samples have previously been taken by the Water Board Rivierenland to check if the effluent does not exceed the values given in the permit to discharge to surface water bodies. The effluent samples were collected at the same locations as where the Water Board took them. At the *Station* helophyte filter (located in the north-west of the neighbourhood) this is in the tank where the pump is located; for the *School* (located in the eastern part of the neighbourhood) helophyte filter this is in the inspection hole constructed at the point where the effluent flows into pipe leading to a stream nearby; and for the *Unie* helophyte filter (located in the south of the neighbourhood) this is at the point where the effluent is discharged directly into the nearby stream. At the *School* helophyte filter the sample was taken directly from the effluent flow. If there was no effluent flow the sample was collected from the water in the pipe leading to the stream as there was a bit of water retention here. As the water is the same as the effluent and a composite sample was made at the end of the day this collection point was also assumed to be representative.
The effluent flow at the *Unie* helophyte filter is constant and therefore samples were collected directly from the point where it flows into the stream. As the pipe from which the effluent flows is above the water surface it was guaranteed that the sample only contained effluent and no water from the stream itself.

4.3.3. Sampling Methodology and Methods

Selection of Sampling Methodology

Sampling is a crucial part of when assessing the characteristics of grey wastewater. Not only is the location where the sample is taken relevant for the eventual outcome of the analyses, but the frequency, time and methodology are also very important. It was not clear which sampling methodology was standard for analysing grey wastewater or the effluent of helophyte filters in literature and the Netherlands. As a result several different options have been analysed below.

Because substances and concentrations in grey wastewater are highly variable and different per source and use (section 6.1; Eriksson *et al.*, 2004; Hernández Leal *et al*., 2007; Jefferson *et al*., 1999; 2004; Li *et al*., 2009b) and the production of this wastewater also varies during the day (section 6.1; Elmitwalli and Otterpohl, 2007; Imura *et al*., 1995; Jefferson *et al*., 1999) reliable measurements are difficult to make. This is not only the case for grey wastewater; Ternes and Jos (2006) point out that substances in urban wastewater differ at different time periods and that a seasonal, weekly, daily and diurnal variations can be seen. Instances are recorded where the characteristics of wastewater changed within a few minutes (even though the flow rate did not change). ISO standards require samples to be taken at a high frequency with an individual analysis to determine the best sampling strategy for a certain wastewater stream at a certain location (Ternes and Jos, 2006). However, as this requires a large amount of financial means it is in most cases not feasible. Instead, general sampling methods have been developed by different authors that each serves a different purpose (See Table 1).

Table 1. Sampling strategy and data interpretation (Taken from Ternes and Jos (2006) and authors quoted therein)

Sampling methodology	Aim	Validity
- Point sampling combined with continuous flow measurement	To establish average "flow to concentration" relationships	Valid for the gross estimate of yearly loads
- Continuous sampling a) time-proportional b) flow-proportional	a) To estimate time-averaged water quality b) To quantitatively assess average water quality and loads	a) Valid for constant discharges b) Valid for variable discharges
- Continuous on-line measurements	To establish realistic pollution including extreme events	Valid for the description of dynamic processes
- Target sampling (e.g. storm event sampling)	To establish, e.g., suspended sediment transport	Valid for, e.g., full transport budgets

Due to the high variation in grey wastewater characteristics, point sampling was deemed not the best choice as different dilemma's developed. The day on which the sample(s) would be taken, as well as the time and the number of samples all became very relevant as the likelihood of collecting a sample with high or low concentrations of one or more parameter is relevant. Furthermore, grey wastewater is not produced in a constant stream into the collection tank. As a result a very high number of point samples would have to be taken from the grey wastewater sewage pipe itself. Not only was this practically not possible as it could not be accessed, but it would also result in a high number of required analyses. This became too expensive (Marsman, 2010a) and thus limited the applicability of the point sampling methodology.

As devices to immediately record grey wastewater characteristics or collect samples automatically are not available for this study (Marsman, 2010b), continuous on-line sampling is not possible.

Target sampling serves a different purpose, namely to collect samples so that the characteristics during an extreme event, or for a certain design, can be determined. In this case extreme events are avoided on purpose to ensure that general representative grey wastewater characteristics are obtained, and how the helophyte filter copes with these. It is out of this scope to analyse how the helophyte filters cope with peak flows or concentrated wastewater. Hence this sampling methodology is also not suitable.

The only remaining sampling methodology left is continuous sampling. The flow-proportional continuous sampling would be best suited to analyse general grey wastewater characteristics as it will give a representative mixture of the wastewater produced. This is because grey wastewater is produced in peak flows, and due to the different sources the peaks can have different compositions. However, as stated earlier, there are no devices available to take these measurements. Hence the only option left is time-proportional continuous sampling.

The samples collected should be mixed, resulting in a 24-hour composite sample. This sample will give the average grey wastewater composition during 24 hours. As the daily produced amount of grey wastewater, as neighbourhood scale, was assumed to be fairly constant this sampling methodology is also valid.

The use of a 24-hour composite sample has more benefits, as it is also used to analyse urban wastewater at sewage treatment plants in the Netherlands (Kujawa-Roeleveld, 2010). The methodology is also used in literature. Hernández Leal, for example, also collected 24-hour mixed samples in her PhD research, thereby easing comparison (Hernández Leal *et al*., 2007; Hernández Leal, 2010). By using this standardised sampling method data gained from this study can be compared more readily with data from other cases.

Actual Sampling Methodology

A 24-hour composite sample is usually collected by means of an automated sampler. Unfortunately this device was not available for this study and hence it was done manually. As one person collected the samples in the field this was practically not feasible to do for several days in a row. Sampling at night was left out from the study as grey wastewater production was assumed to be minimal in the neighbourhood during this time period, and a compromise therefore was that the samples were collected between 09:00 and 20:00 thereby creating an 11-hour sample. The sampling started at 09:00 as the samples of the previous day had to be delivered to the laboratory between 07:00 and 08:00. It was not possible to do this at another time due to the opening hours and sampling frequency. The sampling was stopped at 20:00 to allow for enough time so that the composite samples could be made, there was enough time to travel back home and store the composite samples in the fridge.
A critical side note here is that the grey wastewater produced in the neighbourhood after 20:00, which can be considerable due to the cooking and showering or bathing then taking place, was not sampled. This is a weak point in this methodology, but no way of sampling this grey wastewater was found. Furthermore, it was assumed that the grey wastewater samples collected in the morning as well as those collected in the early evening would also contain grey wastewater from the showers, kitchen and perhaps laundry as these activities can also take place at these times (although less extensive) and the collection tanks serve as a buffer.

As the first sampling round started at 09:00 the morning peak in grey wastewater was just missed; this was probably pumped out of the collection tank on the helophyte filter around 07:00. The evening peak in grey wastewater production was captured partially as it starts around 17:00 and can last up to 22:00 (Dijk, 2007). Depending on local water use and the travel-time of the grey wastewater from the house to the collection tank, this could range between the beginning and the top of the grey wastewater production peak. It was outside the scope of this study to investigate this more deeply.[6]

The sampling took place in weeks 4 and 5 (24-1-2011 till 3-1-2011). The influent of the three helophyte filters was sampled on Monday, Tuesday and Wednesday of week 4 and on Monday, Wednesday and Thursday of week 5 due to illness on Tuesday. As the retention time of the helophyte filters was calculated to be at least 24 hours, the effluent was sampled on Tuesday, Wednesday and Thursday in

[6] It is recommended to gain a better insight in local water use, as well as the time that the grey wastewater spends in the sewage system as this can result in better and more in-depth studies and analyses.

week 4 and on Wednesday, Thursday and Friday in week 5. Hence the influent sample collected on Monday in week 5 and the effluent sample collected on Wednesday in week 5 could not be used to assess the removal capacity of the helophyte filters. However, these analyses were used to generate more general data on the influent and effluent characteristics.

Sampling Round and Measurement Devices

A sampling round started each hour at the *Station* helophyte filter if either influent or effluent was sampled as this took about 40 to 55 minutes. If both influent and effluent was sampled one sampling round lasted 1.5 hours.
At the beginning of a sampling round one or two aliquots were collected and labelled (one influent and/or one effluent). At the same time, the aliquot was used to measure and record the dissolved oxygen and temperature with one probe (OxyGuard) and the pH with another (WTW pH 315i with WTW SenTrix 21 pH-Electrode and a WTW TFK 150 temperature probe). The aliquots were stored in a cooler box (Coleman Poly-Lite 48QT) with icepacks (3x Gio'Style 400, 1x Ghiaccio 350 and 6 frozen 500ml aliquot-containers filled with water per cooler box) to preserve them. Each helophyte filter had its own cooler box to prevent possible mix ups. The temperature inside the car, in which the cooler boxes were stored, was recorded as well as the temperature inside the cooler boxes as this should not exceed 5 degrees Celsius to preserve the aliquots. This was measured with a data logger (Voltcraft Thermologger 309) with four sensors (K type). There was one sensor was in each cooler box and one lying loose in the car.

After the sampling at the *Station* helophyte filter was finished, the influent and effluent of the helophyte filters at the *School* and *Unie* were sampled likewise. The sampling round was finished when the dissolved O_2, temperature and pH values were recorded and the aliquots of the *Unie* helophyte filter were placed in the cooler box.

Collection of aliquots

Each aliquot was taken at a depth of 0.2 to 0.6 metres under the water surface, depending on the water depth in the tank at that particular moment. This was done in the following way (DEP, 2008; EPA, 2004):

1. The depth of the water at the sampling point was checked.
2. The sample-collection container was submerged to the appropriate depth.
3. The sample-collection container was inverted to allow the water to flow into the sampling container. If there was water flow the top of the sampling container was pointed into the flow.
4. The filled sample-collection container was returned to the surface quickly.
5. The sample-collection container was swirled to ensure that it was rinsed, after which it was emptied gently back into collection point
6. The sample-collection container was then filled as stated above and brought back to the surface.
7. The water in the sampling-collection container was used to rinse the aliquot-container, after which the water was gently poured back into the sampling point.
8. The sampling container was filled again as described above, after which the water was slowly and gently poured into the aliquot-container.
9. The dissolved O_2, temperature and pH of the aliquot were measured. When readings were constant they were recorded.
10. The probes were rinsed with demineralised water before and after measurements were taken.
11. The water in the aliquot-container was
12. The aliquot-container was capped with as little headspace as possible.
13. The aliquot-container was labelled appropriately and stored on ice in a cooler box.
14. The air temperature in the cooler box was recorded.
15. The outside air temperature was recorded.

Two of the three collection tanks (where influent is collected) are more than three meters deep. An aliquot was collected by means of a pole with a cup on the end that was lowered into the tank by means of a rope.

At the end of the sampling day all aliquots for the influent were mixed in an intermediate container (a clean bucket). The aliquot-containers were swirled to ensure that all particles flowed out of the container. The composite sample in the bucket was mixed and then poured into the different composite sample containers provided for the different analyses. The sample in each final composite sample container was preserved according to the parameters that it was analysed for to stabilise the parameters (Table 2).

Each container was labelled, sealed and returned to the appropriate cooler box.

This procedure was done for both the influent and effluent of all three helophyte filters. This resulted in a total of 18 11-hour composite samples per week, and 36 for the whole study period.

Table 2. Conservation of different composite samples (Berenpas, 2011; Kleibergen, 2011b)

Final Composite Sample Container	Parameter	Conservation
1	BOD_5	Cooling, no air entrapment
2	COD, TKN, P-Total	Cooling, Acidification with 1 ml H_2SO_4 per 500 ml sample
3	NO_3^-, NO_2^-	Cooling, filtration with 0.45µm
4	NH_4^+	Cooling, filtration with 0.45µm
5	TSS	Cooling
6	Pathogens (*E.coli*)	Cooling

Each composite sample was labelled in the following way:

- Location-Influent/Effluent-Date (i.e. Station-Influent-24-1-2011).

It also included a form including the following points:

- Sample ID
- Date and time of sample collection
- Sampling location
- List of aliquots analysed at the different time periods with the recorded O_2, temperature, pH, and cooler box and outside temperature values.

The icepacks and bottles of frozen water were placed in the freezer at night. The composite samples were stored in a refrigerator overnight as well.

Transportation and Delivery

After the final composite samples were made, these samples were stored in the cooler boxes and fridge before they were delivered to the laboratory of Water Board Rivierenland the following morning. It was ensured that this was done with 24 hours after the composite samples were made.

Analyses

Water Board Rivierenland agreed to perform 36 analyses. Each analysis consisted of the different parameters mentioned earlier. This was done by Dutch standards.

The results of the different analyses were ready two weeks after the last composite sample was delivered to the laboratory.

For analysing the lab results the characteristics of the potable water supplied to Lanxmeer could be useful. As Vitens nv provides the potable water to the neighbourhood, it was contacted for the characteristics of the drinking water supplied to the neighbourhood during the time of the research. They agreed to provide these free of charge. This list has been included in Appendix 7.

Materials

The list of materials was needed for collecting the samples is provided in Appendix 2.

Costs

The costs of the field work, with the different parties that paid these are presented in Appendix 3.

Part B. Literature Studies

5. Helophyte Filters-General Functioning and Usage

In nature helophyte filters occur as wetlands at transitions between land and water. Although these areas can fall dry certain times of the year, on average a water table is present above the soil surface. In nature wetlands exist in different forms such as swamps, marshes, bogs, pools and flooded grasslands (Gopal, 1999; Kivaisi, 2001; Nanninga, 2009; Vymazal, 2005a). They exist in both saline brackish and freshwater environments.

Helophyte filters are categorized according to the macrophytes that are planted in the bed, or medium, as well as the predominant water flow. The Free Water Surface (FWS) helophyte filter is similar to natural wetlands as the water flows from an inlet to an outlet over the surface of the soil. The macrophytes present in a FWS helophyte filter are usually emergent, submerged, free floating or rooted in the soil with floating leaves.

In a Sub-Surface Flow (SSF) helophyte filter the macrophytes are only of the emergent type. As the name already shows, the water flows under the surface of the soil, through the medium. This medium is usually course sand or gravel. The water either flows horizontally (H-SSF) or vertically (V-SSF) (Sleytr *et al.*, 2007; Vymazal, 2005a; 2005b; Vymazal *et al.*, 2006) (see Figure 4). SSF helophyte filters require less land surface than a FWS helophyte filter as there is more area of contact between the medium, bacteria and plant roots and the water, resulting in more efficient pollutant removal (García *et al.*, 2008; Sleytr *et al.*, 2007).

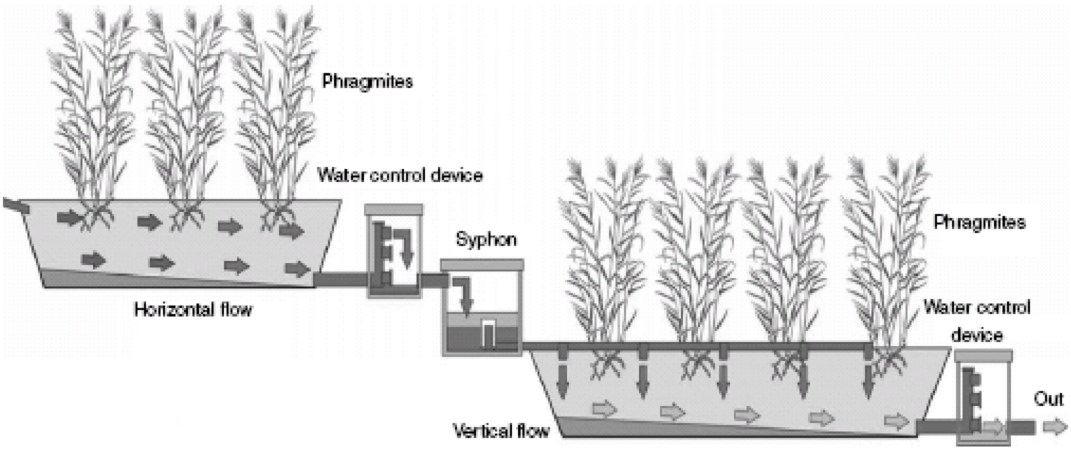


Figure 4. Horizontal and Vertical Sub-Surface Flow helophyte filters, shown in sequence (Masi and Martinuzzi, 2007)

5.1. Historical Development

Macrophytes were first used to remove pollutants from waters in the 1950's at the Max Planck Institute in Plön, Germany by Dr Käthe Seidel. The experiments were intensified in the 1960's as she, in collaboration with Dr Reinhold Kickuth of the University of Göthingen, showed that macrophytes could remove pollutants from agricultural and domestic wastewater (Cooper, 2009; Haberl *et al.*, 1995; Sahtouris, 1990; Vymazal *et al.*, 2006). In the 1970's Kickuth developed a one-stage H-SSF helophyte filter with soil as the medium, which was called a root-zone method or root-zone treatment plant. Here mechanically pre-treated wastewater was used as influent (Haberl *et al.*, 1995; Wallace, 2004). Seidel developed a two stage system with macrophytes planted in shallow embankments. The first stage was a vertically percolating filter planted with *Phragmites australis* and the second stage a horizontal flow bed planted with other emergent macrophytes (Haberl *et al.*, 1995; Vymazal *et al.*, 2006). She used raw wastewater.

Towards the end of the 1960's the first helophyte filters were being used to treat wastewater in, amongst others, Denmark and the Netherlands. Germany followed in the 1970's. In the Netherlands the first helophyte filter, a FWS, was constructed in 1967 at a campsite in Flevoland. In the following years the number grew to around 20 (Cooper, 2009; Haberl *et al.*, 1995; Vymazal, 2005a; Vymazal *et al.*, 2006).

Although the removal of pollutants from wastewater was very good, the early systems (H-SSF) used fine soils as a medium and thus clogged quickly due to the low permeability, resulting in overland flow. This lowered the treatment efficiencies and the designs were amended. In the 1980's helophyte filter builders in the UK decided to use gravel as medium and the surface was made horizontal instead of sloped. Unintended surface flow was hence discouraged (Cooper, 2009; Vymazal, 2005a). As helophyte filters were further improved they rapidly spread across Europe as an ecological wastewater treatment technology. Most of these helophyte filters were of the H-SSF type.

During the 1990's the removal Nitrogen pollutants such as Ammonium (NH_4^+), Nitrite (NO_2^-) and Nitrate (NO_3^-) from wastewaters became increasingly more relevant as the removal of Biological Oxygen Demand (BOD) and suspended solids alone was no longer sufficient. Other systems than the H-SSF helophyte filter were needed and the V-SSF helophyte filter came into the picture again (Cooper, 2009; Haberl *et al*., 1995; Vymazal, 2005a).

Although the FWS helophyte filter allows for good nitrification and denitrification processes (Kadlec and Knight, 1996; Kadlec *et al.*, 2000) and is very effective at removing suspended solids and achieving sustainable levels of Phosphorus (P) removal, they are very land-intensive. For treating the same amount of wastewater twice the area of an H-SSF helophyte filter is needed (Tsihrintzis *et al*., 2007). In turn, an H-SSF helophyte filter is approximately twice the size of a V-SSF helophyte filter. The main reason for this is that the wastewater flows through the medium in a SSF helophyte filter instead of over it, as is the case with a FWS helophyte filter. Thus the hydraulic conductivity of the SSF helophyte filter is much higher than the FWS system and the filtration and surface bound reactions are therefore higher (García *et al.*, 2008) resulting in a more efficient removal of pollutants (Dallas *et al.*, 2004; Reinoso *et al.*, 2008; Tsihrintzis *et al*., 2007). In turn, the wastewater in a V-SSF helophyte filter is exposed to more oxygen than the wastewater in an H-SSF helophyte filter, resulting in better pollutant removal efficiencies.

V-SSF helophyte filters allow for nitrification and BOD removal but have poor suspended solids-removal, whereas H-SSF have good BOD and suspended solids-removal but poor nitrification rates. Denitrification does occur in this type of helophyte filter (Cooper, 2009). Hence, as was already predicted by Seidel in the 1960's and described by Wood (1995), the V-SSF and H-SSF are very complementary. In these hybrid systems nitrification first takes place in the V-SSF bed, and consequently denitrification in the H-SSF bed. Furthermore, due to the higher effectiveness per unit of area these systems became the preferred wastewater treatment system in the 1990's (Haberl *et al*., 1995; Vymazal, 2005a; Vymazal *et al*., 2006).

Most of the hybrid systems are being implemented throughout Europe; namely in Germany, France, and the UK, but also in Slovenia, Austria, Norway and Ireland. In fact, these hybrid systems can be found in most European countries (Vymazal *et al*., 2006). The V-SSF helophyte filter followed by an H-SSF helophyte filter is the most common setup as it removes nitrogen from the wastewater at the most efficient rates (Haberl *et al*., 1995; Vymazal, 2005b). If the influent has high suspended solids-concentrations the opposite combination (H-SSF - V-SSF) is also possible as the H-SSF helophyte filter is more effective at removing suspended solids.

FWS helophyte filters are being combined with V-SSF, H-SSF, or hybrid systems, as well as waste stabilization ponds (WSP's), due to their positive influence on the removal of pollutants and pathogenic organisms (Reinoso *et al.*, 2008; Vymazal, 2005a). However, this does not occur often due to the amount of space needed.

5.2. General Functioning

5.2.1. Processes

The main processes resulting in the removal of pollutants from wastewater in a helophyte filter are precipitation and sedimentation, adsorption, chelation, filtration, oxidation and (micro) biological uptake and/or breakdown of pollutants (Figure 5). The symbiotic relationships between the macrophytes and microorganisms living in their root zones play a key role in removing organics from the wastewater. Other mechanisms that influence the purification of the wastewater are ultra violet radiation, temperatures, physicochemical (anaerobic and aerobic) reactions and predation (Ciria *et al.*, 2005; Denny, 1997; Greenway, 2005; Gopal, 1999; Nanninga, 2009).

The major drawback on SSF helophyte filters is that the sedimentation, entrapment of solids, formation of bio film and chemical precipitation result in clogging. As the spaces between the media become smaller the hydraulic conductivity decreases, resulting in an increase in flow velocity and a lower hydraulic retention time (HRT) (Caselles-Osorio and García, 2007; Carty *et al.*, 2008; Nanninga, 2009; Oirschot, 2010). As the removal of pollutants is directly influenced by the hydraulic regime predominant in the helophyte filter, this should be managed closely by maintaining water depth, the HRT and vegetation status (García *et al.*, 2008). Several studies mentioned by Caselles-Osorio and García (2007) have shown that a 25 per cent reduction in initial volume can be observed. Oirschot (2010), on the other hand, mentioned a possible decrease of 90 per cent in pore volume, based on his personal experiences in the field. The roots of the macrophytes play an essential role in maintaining hydraulic conductivity as they prevent the medium from clogging (Cooper, 2009).

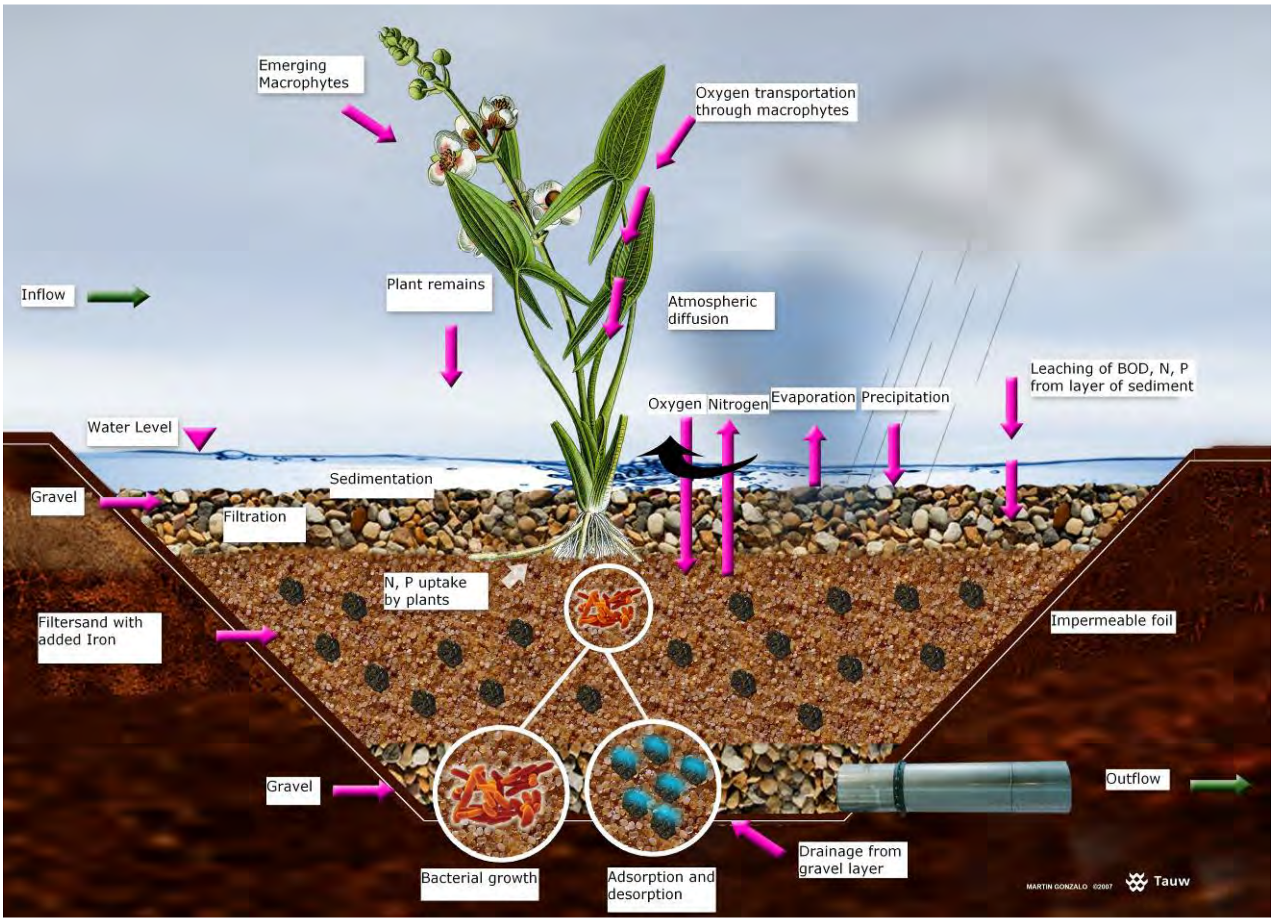


Figure 5. Processes taking place in a helophyte filter (Gonzalo Wennekes, 2007)

Physical

The physical processes that take place in a helophyte filter are filtration, sedimentation and physical adsorption (Nanninga, 2009). The macrophytes were accredited with the purification of the wastewater in the past. However, it is now known that this is not entirely the case but that the roots and stem movement by the wind prevent the beds from clogging and maintaining the hydraulic conductivity (Cooper, 2009; Gopal, 1999; Hiley, 1995; Karim *et al.*, 2004; Song *et al.*, 2006). Vymazal (2005b) and Hiley (1995) have noticed that effluent has higher dissolved oxygen levels if the macrophyte roots are allowed to grow freely. As the main physical processes are filtration and sedimentation, suspended solids are primarily removed by these processes. P is mainly removed by adsorption to Iron (Fe) particles that are sometimes added to the medium.

The main physical factor influencing the treatment efficiency is the HRT, which is the average time that the wastewater stays in the helophyte filter (García *et al.*, 2008; Reinoso *et al.*, 2008; Scott *et al.*, 2003; Sousa *et al.*, 2001; Stott *et al.*, 2003). The hydraulic loading rate (HLR), which is the rate at which the influent is discharged in the helophyte filter, can also influence the level of treatment that the helophyte filter can accomplish (Burkhard *et al.*, 2000; Eliasson, 2002). By doing this in an intermittent way air will be drawn into the bed as the water level lowers. Oxygen in this air can then allow for reactions needing an aerobic environment and feed (micro) biological components and bacteria. It is possible to have anaerobic reactions in an overall aerobic environment. This is possible as anaerobic conditions can occur in small pockets not exposed to the air as well as the water layer at the bottom of the bed (Vymazal and Kröpfelová, 2008).

Chemical

Precipitation, chemical adsorption and aerobic, anaerobic and photochemical reactions are chemical processes taking place in a helophyte filter (Nanninga, 2009). The combination of aerobic and anaerobic reactions in the bed can partly be attributed to the macrophytes but mainly to the intermittent flow of wastewater. Macrophytes allow for oxygen transfer between the air and the roots via their hollow stems. This enables the growth of biofilm and bacteria in their rhizospheres (Caselles-Osorio and García, 2007; Soto *et al.*, 1999). The conditions outside of the rhizospheres are generally anaerobic if wastewater is flowing through the bed.

Biological

Biological processes taking place in a helophyte filter are bacterial metabolism, plant uptake, natural die-off, formation of biofilm and predation and microbial degradation (Nanninga, 2009). The surface areas of the plant parts underwater as well as the medium through which the wastewater flows allow for the formation of biofilm. Soto *et al.* (1999) mention that there is more microbiological activity in biofilms present on roots than in biofilms on gravel or sand. This can be attributed to the presence of oxygen in these rhizospheres. As the hydraulic conductivity between the medium and plant roots is negligible in surface flow helophyte filters this is more relevant in SSF helophyte filters (Carty *et al.*, 2008; García *et al.*, 2008).

5.2.2. Fate of Different Characteristics in Helophyte Filters

Biological Oxygen Demand and Chemical Oxygen Demand

Dissolved oxygen is needed to remove certain pollutants from wastewater. Hence the amount of oxygen that is needed to remove the pollutants from the wastewater can be used as an indicator for how polluted the wastewater is. Two of the tests for determining the amount of dissolved oxygen that is needed to remove organic pollutants are the Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Both tests indicate the amount of organic pollutants, consisting of proteins, carbohydrates and lipids as well as small amounts of synthetic organic compounds that are present in the wastewater but in different ways (Metcalf and Eddy, 2004).

The BOD test determines how much dissolved oxygen is used for the biological degradation of the organic matter by microorganisms present in the wastewater during a certain time period. In general the time period is five days (BOD_5) although seven and 20 day test are also used (BOD_7 and BOD_{20}, respectively). Needless to say, although the latter two are more accurate than the BOD_5 test, they are also more time consuming and hence less practical (Metcalf and Eddy, 2004).
The aerobic biological degradation consists of three reactions; 1. Part of the organic compounds are oxidise to obtain energy for cell maintenance and the synthesis of new cell tissue by the microorganisms; 2. The synthesis of new cell tissue requires another part of the organic compounds to be converted into cell tissue; 3. After all organic matter is used up the microorganisms begin to consume their own cell tissue to obtain energy for cell maintenance, thereby consuming more dissolved oxygen. The BOD measured is all dissolved oxygen needed to complete these three reactions (Metcalf and Eddy, 2004).

The COD test is the same principle as the BOD test, but instead of waiting for the aerobic biological degradation to complete, the dissolved oxygen equivalent of the organic material is determined chemically. This is done with dichromate in an acid solution. The COD test generally takes an approximate 2.5 hours although there are quick tests that take 15 minutes (Metcalf and Eddy, 2004).

As the amount of dissolved oxygen is measured in the COD test it would be expected that the values would be the same as those from the BOD test. However, this is rarely the case as COD levels are generally higher. This is due to three reasons; 1. There are organic substances that are difficult to oxidise biologically; 2. The dichromate can react with inorganic substances thereby increasing the apparent organic content of the wastewater; 3. The microorganisms used in the BOD test could be poisoned by certain organic substances present in the wastewater, thereby lessening the biological degradation in the BOD test (Metcalf and Eddy, 2004).

In general BOD/COD ratios are between 0.3 and 0.8, with 0.5 indicating that good aerobic biodegradability is possible. If the ratio is too low there might be toxic component in the wastewater or specific microorganisms needed for the breakdown (Metcalf and Eddy, 2004).

The organic pollutants that are indicated by the BOD and COD test are generally removed throughout the whole helophyte filter although rates might be higher in the top half as there are higher oxygen concentrations present. Higher temperatures will increase the rate of the biological degradation and hence the consumption of dissolved oxygen. If the wastewater is deprived of oxygen and comes in contact with the outside air noxious odours may be produced. Hence in warmer climates or seasons the aerobic biological degradation takes place at a relative higher rate, resulting in a higher chance of noxious odour production (Metcalf and eddy, 2004).

Nitrogen

Nitrogen (N) enters domestic wastewater mainly via urine but is also present in household chemicals used. The forms in which it occurs are Ammonium (NH_4^+) and organic nitrogen. Nitrite (NO_2^-) and Nitrate (NO_3^-) are seldom in high concentrations in influent as they are the results of different biological reactions (Metcalf and Eddy, 2004; Vymazal and Kröpfelová, 2008).

The Nitrogen cycle is shown in Figure 6, where it starts with plant material and organic waste. Although this is not present in high concentrations in domestic wastewater the figure does provide a good insight in the forms that N occurs in during the different phases.

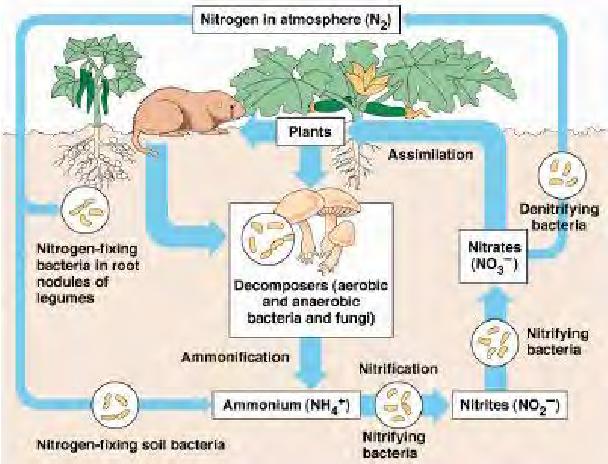


Figure 6. Nitrogen cycle (Campbell *et al*., 1999)

Organic matter containing N is degraded to the inorganic form of NH_4^+ by an aerobic process called ammonification. N can also be present as ammonia (NH_3) instead of (NH_4^+) but this is determined by the pH of the water or soil.[7] If the surroundings are acidic (low pH) there is more NH_3. NH_4^+ is present in more basic environments. With a pH of around seven NH_4^+ is more commonly found in wastewaters. NH_4^+ is usually formed into NO_3^- by nitrification, with NO_2^- being an intermediate form. Autotrophic bacteria are the main driver behind these processes, meaning that they take place in an aerobic environment. The final stage in the nitrogen cycle is where NO_3^- is transformed into N_2 through denitrification. This is an anaerobic process where the bacteria gain their needed oxygen from the NO_3^-. As these bacteria are heterotrophic, they also need the presence of Carbon (C) in order to produce N_2 (Lim *et al.*, 2001; Metcalf and Eddy, 2004; Vymazal and Kröpfelová, 2008).

Although plants prefer NH_4^+ over NO_3^- as NH_4^+ can readily be incorporated into amino acids during biosynthesis, NH_4^+ is poisonous to plants when they are exposed to it for a prolonged period. NO_3^- can be stored without doing any harm but first needs to be reduced before it can be used. When plants die off C and N are made available through decomposition. N is reintroduced as NH_4^+ into the cycle by ammonification as bacteria break down the detritus (Metcalf and Eddy, 2004; Vymazal and Kröpfelová, 2008).

Phosphorus

Phosphorus (P) is mainly present as orthophosphate (inorganic, stable), organic phosphate (phosphate bound to organic particles) and as polyphosphate (unstable compound consisting of several P atoms) in wastewater. In the Netherlands its main origin are dishwashing detergents and food particles. Chemicals such as those used for softening water can also be a (minor) source. Laundry detergents are no longer a source in the Netherlands as Dutch legislation forbids the use of phosphates in these products. This, on the other hand, is not the case in all countries. Especially those in the developing world still allow the use of P for laundry detergents, resulting in higher P concentrations in wastewater there, compared to the Netherlands (see sections 6.2.3 and 6.4) (Metcalf and Eddy, 2004).

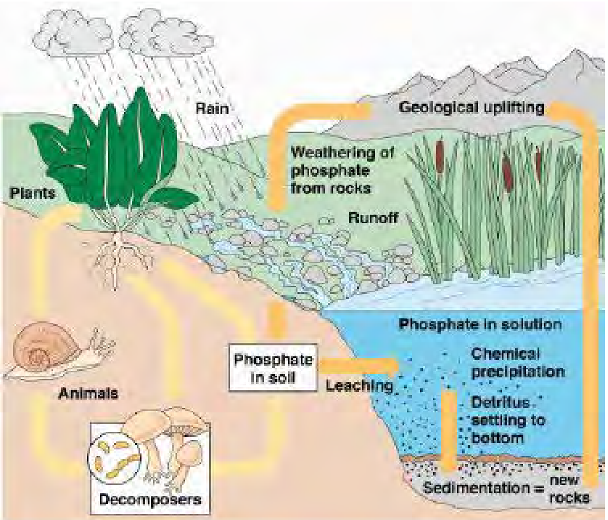


Figure 7. Phosphorus cycle (Campbell *et al*., 1999)

The P cycle is different from the N cycle as there is no major gaseous phase (Figure 7). Hence the cycle is usually local. P is highly reactive and is always bound to another element. In nature it is most commonly bound to oxygen to form phosphate (PO_4^{3-}) (Campbell *et al*., 1999).

P is not broken down by bacteria like N. Instead, there are many different processes resulting in its removal from wastewater. These mechanisms either take place on a large scale but slow rate, or vice versa, thereby complicating matters as to which process is responsible for what result. These mechanisms are; 1. Peat/soil accretion (high scale, low rate); 2. Adsorption to soil (low to moderate scale, moderate rate); 3. Precipitation (moderate scale, fast rate); 4. Plant uptake (low to moderate scale, slow rate); 5. Detritus sorption (low scale, slow rate); 6. Microbial uptake (very low magnitude, slow rate) (Vymazal and Kröpfelová, 2008).

[7] The relation is shown in the following formula: $NH_3=(NH_4^+ x K_a)/H^+$, where $K_a=5.62x10^{-10}$ and $H^+=10^{(-pH)}$ (Metcalf and Eddy, 2004).

The organic P is removed from the wastewater through peat/soil accumulation. This is a very slow process in which the P is stored permanently (1 gr/m^2/yr). The P that binds to mineral surfaces is soluble inorganic P and only takes place when there is enough Al, Fe, Ca and Mg present in the soil. Precipitation, which is a reaction of inorganic P with Fe^{3+}, Al^{3+}, Ca^{2+} or Mg, results in amorphous solids. Plant uptake, detritus sorption and microbial uptake are less important in removing P from wastewater than the three processes described previously, although the rates at which this happens do differ per location. The orthophosphates (e.g. HPO_4^{2-}, $H_2PO_4^-$) in wastewater are freely available for plant uptake. This is done mainly via their roots. The P becomes organic again when the plant dies and is broken down (immobilisation). Microbial activity is responsible for the mineralisation of P (change of organic to inorganic) (Song *et* al., 2007; Vymazal and Kröpfelová, 2008).

Helophyte filters can suddenly release (large) amounts of P due to changes in pH or redox potential. Thereby the state of Fe^{3+}, Al^{3+}, Ca^{2+} or Mg is changed as well as the mineralisation rate of P. The drying out of a helophyte filter before a flooding can result in desorption of P as well as increased mineralisation. The latter will result in the release of dissolved inorganic P (Song *et al*., 2007).

Total Suspended Solids

The solids present in grey wastewater are, clothes particles, skin cells, hairs, food residues and colloidal material. In domestic wastewater faecal matter form part of the solids as well. The organic/inorganic ratio of solids in domestic wastewater is generally about 1:1, although this differs per case. Coarse materials are often removed before the wastewater is analysed for solids, after which a filter is used to separate the Total Suspended Solids (TSS) from the Total Dissolved Solids (TDS). This filter usually has a pore size varying from 0.45 µm to 2.0 µm (Metcalf and Eddy, 2004).

Although there are several drawbacks to using the TSS test for describing wastewater characteristics (such as different filter sizes, collection of particles and clogging of filter during filtration, different results for different apparatus's and no indication on the size distribution of the particles), it is universally used with the BOD test to indicate the state and need for treatment of wastewater (Metcalf and Eddy, 2004).

The particles are removed from the wastewater by different processes taking place in a helophyte filter. Next to filtration through the gravel and sand there is also adsorption, sedimentation, and biological degradation of organic particles.

Oxygen

Oxygen is added to the wastewater in three different ways; 1. Transfer of oxygen from the air to the water when there is contact between the two; 2. Via the macrophytes in the helophyte filter that transfer oxygen to their roots; and 3. Oxygen already present in wastewater (Tyroller *et al*., 2010).

Dissolved oxygen concentrations in wastewater will be low as this is consumed by the aerobic biological degradation taking place. This process is therefore considered to be minimal in oxygen addition to wastewater. The role of macrophytes in introducing oxygen to wastewater is still under discussion and complicated by the high variance of oxygen release, seasonal differences, different experimental techniques as well as the complexity of root structures and physiological processes (Brix, 1997; Tyroller *et al*., 2010). Nevertheless, there is proof of higher oxygen concentrations in the rhizospheres, although the relevance of these processes is still controversial. The last process, where oxygen is transferred from the air to the water when both are in contact is thought to be the most relevant (Tyroller *et al*., 2010). This is encouraged by an intermittent inflow as air is drawn into the bed when the water level drops. When a new batch of wastewater is applied it will infiltrate into the bed, thereby passing the air pockets, filling them and creating a slight airflow upwards.

Pathogens

Pathogens consist of several different microorganisms such as bacteria, protozoa, helminths and viruses. Those found in domestic wastewater are excreted by infected humans or animals (Metcalf and Eddy, 2004). Pathogenic growth in wastewater can be encouraged by P, NH_4^+ and nutrients for these pathogenic organisms present in wastewater as well as mild temperatures (Dixon *et al*., 2000; Paruch, 2011; Rose *et al*., 1991).

Different processes take place in the removal of pathogenic organisms from wastewater. These are solar irradiation, temperature, humidity, filtration, adsorption, sedimentation and biological reactions such as antibiotics being released by the macrophytes (Brix, 1997; Greenway, 2005; WHO, 2006). Although these factors generally have a negative effect on the survival of pathogenic organisms they can also encourage pathogenic growth if conditions are right (e.g. temperature, where low are lethal and moderate are stimulating). This will differ per location and circumstance, but overall helophyte filters are suitable for removing pathogenic organisms (García and Bécares, 1997; Hench *et al.*, 2003; Perkins and Hunter, 2000; Stott *et al.*, 2003; WHO, 2006).

WSP's are generally credited with the highest removal rates of pathogens (Stott *et al.*, 2003). This can be related to the different processes such as adsorption to solids, sedimentation, solar irradiation, predation, physicochemical mechanisms and toxic conditions created by algae that can take place in the water bodies (Gopal, 1999; Hiley, 1995; Karim *et al.*, 2004; Reinoso *et al.*, 2008; Song *et al.*, 2006; Stott *et al.*, 2003). SSF helophyte filters are better at removing coliphages and protozoan cysts as there is more filtration taking place when the wastewater flows through the medium (Dallas *et al.*, 2004; Reinoso *et al.*, 2008).

Sedimentation and filtration rates are highest in the first stretch of an H-SSF helophyte filter and at a medium depth of 10 to 20 cm for the V-SSF helophyte filter (García *et al*., 2005; Sleytr *et al*., 2007; Stott *et al*., 1999). EPA (1993) mentions that SSF helophyte filters are generally capable for reducing the faecal coliforms by 1 or 2 log.
Paruch (2011) researched the survival of *E.coli* in the medium of an H-SSF helophyte filter and found that most numbers occur at the 35-50 cm depth, whereas survival rates are highest in the top 20 cm. This would indicate the importance of aerobic conditions for pathogenic survival. García *et al*. (2008) found no significant variations in bacterial removal during seasonal changes, although Paruch (2011) does mention that temperature differences in the medium make a difference in survival.

5.3. Design and Construction

5.3.1. Dutch Legislation

In 1998 Dutch guidelines for designing a V-SSF helophyte filter were formed (VROM and KIWA, 1998). These guidelines were specific for V-SSF helophyte filters as this types of helophyte filter was increasingly being implemented in the Netherlands due to its removal efficiencies. Furthermore, most knowledge on wastewater treatment with helophyte filters concerned the V-SSF type. These guidelines not only specified the surface areas needed per p.e., but also the depth of the helophyte filter, the dimensions of the distribution and drainage pipes, pumping regimes, the construction materials used, operation and maintenance requirements and pre- and post-treatment options. All but the latter are discussed in the following sections. An overview of the annual operation and maintenance requirements, as prescribed by the Dutch guidelines, are given in Table 30 in Appendix 4.

In the Netherlands only the V-SSF helophyte filters have been tested and certified for domestic wastewater treatment in cases where the polluter cannot be connected to the conventional sewage system (e.g. distance to nearest sewage pipe is more than 40 metres). The V-SSF helophyte filter has been accredited with the IBA Class IIIB label, meaning that they can reduce the BOD, COD, N, P and TSS concentrations to certain levels (Table 3). The IBA Class IIIB label requires most pollutants to be removed as the accreditation of Classes I, II and IIIA only prescribe the reduction of BOD and COD, BOD, COD and TSS, and BOD, COD, TSS and N, respectively.

Table 3. Pollutant concentrations in effluent of an IBA Class IIIB wastewater treatment technology, in any 24 hr. composite sample (KIWA, 2000)

	Units	Concentration
BOD_5	mg/l	20.0
COD	mg/l	100
NH_4^+	mg/l	2.00
P-total	mg/l	3.00
TSS	mg/l	30.0

In order to gain this label, the V-SSF helophyte filter has to treat influent which was similar to domestic wastewater (Table 4).

Table 4. Influent concentrations that a V-SSF helophyte filter should treat as prescribed by KIWA (2000) (wastewater production is assumed to be 150 l/c/d)

	Units	Concentration
BOD_5	mg/l	250-400
COD	mg/l	600-1000
N-Total	mg/l	50-100
P-total	mg/l	6-16
TSS	mg/l	300-450

The V-SSF helophyte filter also has to undergo stress situations, such as prolonged draught and peak loads (four times the design load for 24 hours) and still produce effluent that complies to regulations as specified by KIWA[8] (2000) (Table 3). The KIWA has also formed a quality label that certifies that the V-SSF helophyte filter has been constructed soundly and with high quality construction materials (KIWA, 2003).

5.3.2. Filter Bed

The dimensions of a helophyte filter as well as the amount of wastewater that is applied on the helophyte filter determine the hydraulic retention time (HRT). This in turn determines how much time the different processes have in order to take place to remove pollutants.

In the case of a SSF helophyte filter the flow rate will decrease if the medium is too course. This will also influence the area on which biofilm can form and to which certain compounds can bind. On the other hand, if the medium is too fine it will clog quickly due to biofilm formation and accumulation of solids, as was the case in the 1970's (see section 5.1) and in Drielanden, Groningen (see last paragraph of section 7.1). This will result in overland flooding and poor removal efficiencies (In this case a FWS helophyte filter will come into existence but these need longer HRT's than SSF helophyte filters, hence the wastewater will not be treated adequately).

The depth of the bed should be more than 0.2 m to allow for proper rooting of the macrophytes and enough medium for the wastewater to flow through. In the case of a FWS helophyte filter the depth of the bed does not matter, as long as it does not leak and gives sufficient support to the macrophytes. The beds of an H-SSF helophyte filter are generally not much deeper than 1.2 m as this is the maximum depth that the roots can grow (Anonymous[9], 2009; Nanninga, 2009).
The total area of the helophyte filter is determined by the characteristics of the influent as well as the number of p.e.'s that produce the wastewater. For grey wastewater treatment with a V-SSF helophyte filter a surface area of 2 m^2/p.e. is maintained, whereas domestic wastewater requires an area of around 4 m^2/p.e.. For an H-SSF helophyte filter these areas are doubled. A FWS helophyte filter, with an assumed water depth of 0.2-0.5 m, requires an area of 10-20 m^2/p.e. for domestic wastewater with long hydraulic retention times (>10 days) (Brix, 2004).

These surface areas are generally based on experience, simple formulas and rules of thumb rather than complex scientifically motivated formulas due to the lack of research (Deun, no date). Practice shows that this does work although Verhoeven (2010) mentioned that the area per p.e. could be larger than is currently used. Reason for this is that there could be individuals who pollute more than average, although he could not back this up with a concrete study as he experienced it in the field. Note that in the report by EPA (1993) several formulas for the design of a SSF helophyte filter, based on Darcy's law, with performances of SSF helophyte filters from the USA, are given.

Table 5. COD and TKN concentrations as well as the total dissolved oxygen demand, in domestic wastewater and grey wastewater as calculated by Wijst and Groot-Marcus (1998) and used in the Dutch wastewater sector.

		Domestic wastewater	Grey wastewater
Wastewater production	l/c/d	134	95
COD	mg/l	749	538
TKN	mg/l	79	4
Total dissolved oxygen demand[A]	mg/l	1110	555

Notes:
A: This is calculated by adding the COD value to 4.57xTKN.

The design of V-SSF helophyte filters in the Netherlands is based on the assumption that one p.e. produces 150 litres of wastewater per day and that the maximum hydraulic load on the helophyte filter should be 60 l/m^2. This results in a surface area of 4 m^2/p.e. when a margin for peak loads is included (VROM and KIWA, 1998). For grey wastewater this surface area is about 60 per cent as it is less heavily polluted. This results in a surface area of about 2 m^2/p.e. (Bril, 2002; KIWA, 2003). The latter value is based on calculations using COD and TKN concentrations as described in STOWA report 1998-40 (Wijst and Groot-Marcus, 1998), which is used as a guideline throughout the Dutch wastewater sector. The amount of dissolved oxygen needed to remove both COD and TKN from grey wastewater is calculated in this report to be about 60-70 per cent of the amount of dissolved oxygen needed to remove COD and

[8] KIWA is the Dutch organisation that tests and certifies water related products for their quality.
[9] This personal communication was with a person who used sources and data from a confidential report belonging to a multi-national company. The person therefore wished to remain anonymous.

TKN from domestic wastewater (see Table 5). Practice has shown that V-SSF helophyte filters half the size of those treating domestic wastewater are suitable for treating grey wastewater.[10]

The surface area of a V-SSF helophyte filter should be calculated for a minimum of 4 p.e.'s and up scaled proportionally. From 50 p.e.'s onwards the V-SSF helophyte filter should be up scaled in steps of 50 p.e.'s (KIWA, 2000).

The Dutch guidelines state that the V-SSF helophyte filter should have a gravel layer (8-16 mm) at the bottom with a minimal depth of 0.2 m. The drainage pipes should be at least 0.05 m below the top of this layer. On top of this gravel layer of a layer of filtration sand (100-500 μm), with a minimal depth of 0.8 m, should be installed. Between these two layers a material should be placed that allows water to pass but ensures that the sand and gravel do not mix (such as root canvas).The distribution pipes are installed in a 0.1 m thick layer of course material such as gravel, shells, straw or woodchips on top of the filtration sand layer (VROM and KIWA, 1998). Sometimes Fe (15 kg/m^3 of sand) and straw (15-20 kg/10m^3 of sand) are added to the filtration sand to bind P and allow for initial biological surface areas in order to promote microorganism growth till the macrophytes are fully established.

5.3.3. Location

One of the main critiques of helophyte filters is their demand for space (Brix, 1997; Deun, no date). In remote areas this will not be much of a problem provided that there is enough flat land for one large or several small beds. Countries where local land and labour prices are relatively low the construction costs can also be kept at a minimum. However, in the Netherlands land prices are high and labour is expensive. This not only affects the choice of helophyte filter, where the most efficient in pollutant removal will be preferred, but also its location. In the Netherlands, land zoned for constructing homes and offices is more expensive than land zoned as nature or urban green, which creates a possibility for lowering construction costs as helophyte filters can be constructed in the latter areas (Jager, 2010). Lastly, urban expansion can result in the helophyte filters, initially located at the fringes of a neighbourhood, being located inside the neighbourhood thereby making the required expansion of helophyte filters to treat all produced wastewater difficult.

Climate factors can have a large influence on the functioning of a helophyte filter. In research conducted by Kampf *et al*. (2003) the wind increased the water depth of a FWS helophyte filter by ten per cent on the downwind side. The different water depth resulted in different HRT's across the helophyte filter. The location of the helophyte filter, and its surroundings, can not only determine the influence of the wind, but also that of the natural water ways (Nanninga, 2008; 2009). Surface runoff patterns should be analysed to make sure that these will not result in a flooding of the helophyte filter. Lastly, the location of the helophyte filter will also influence the ease with which operation and maintenance procedures, such as mowing the vegetation, can be performed (Hooijer, 2010a).

5.3.4. Pumping and Macrophytes

The location of the helophyte filter as well as its surroundings (where the influent comes from and where effluent should go) determine the need for pumping. When deciding on the use of a pump, aspects such as energy, operational and maintenance skills, availability of spare parts, the technology to regulate the pumping and notify the operator of errors become critical for the functioning of the entire wastewater treatment system.

Dutch guidelines prescribe that a V-SSF helophyte filter should receive influent twice per day (24 hr.). The distribution pipes should lay 0.7 m to 1 m apart; have a diameter of 32-40 mm and perforations of 6-10 mm. The distance between these perforations should be a maximum of one metre. These pipes should be fitted without glue to allow for maintenance and renewal procedures. The drainage pipes should have a diameter of 80-100 mm with a maximum distance between them of 1 metre (VROM and KIWA, 1998).

Phragmites australis (Common Reed) is recommended by Dutch guidelines to be used as the macrophyte. The initial planting density should be 4-6 plants per m^2 and if cuttings are used this is 6-10 cuttings per m^2. The planting should be done in spring. Although weeds can grow in helophyte filters, their influence on pollutant removal efficiencies has not been investigated in-depth and it cannot be stated that this is negative (Brix, 1997).

Although the Dutch guidelines recommend the use of *Phragmites australis*, there are other macrophytes that can be used as well. Belmont *et al.* (2004) have shown that ornamental flowers (*Zantedeschia aethiopica* and *Canna flaccida*) can grow in a SSF helophyte filter. Duckweed (*Lemnaoideae*), if harvested periodically, has been known to remove N and P from WSP's and FWS helophyte filters. Vries *et al*., (2007) mention three other macrophytes with different characteristics. Cases with these macrophytes

[10] The formulas used to calculate the areas needed to remove this COD could, unfortunately, not be found.

can also be found in literature. *Arundo donax* (Giant Reed) is known for being a macrophyte that is space-competitive and which grows in dense stands thereby not being prone to weed invasion. *Typha latifolia* (Reed Mace, Cattail or Bull Rush) is a good macrophyte for FWS helophyte filters and it is said to be efficient in P-accumulation. *Symphytum officipale* (Common Comfrey) is native to Europe and grows well in shady areas.

The macrophytes used as well as (local) needs will determine if the clippings can be reused or need to be discarded. Although the clippings can be perceived as chemical waste due to the uptake of pollutants from wastewater, this was contradicted by a study conducted for the municipality of Groningen. The vegetation growing on a bank next to a highway, which was continually exposed to surface runoff containing heavy metals, did not contain higher pollutant levels than the same vegetation not exposed to this surface runoff (Jager, 2010).[11]
The clippings of the ornamental flowers used by Belmont *et al.* (2004) were sold on a local market for income. Vries *et al*. (2007) have shown that the clippings of macrophytes can be pulped to provide cellulose fibres for the paper as well as cement and brick making industries. Another income generating activity is the use of clippings or harvested plants (as is the case with *Lemnaoideae*) for biofuel production. If the clippings are dried and pressed into compact briquettes they can also be sold as fuel for fires. The clippings can also be pressed into bales for storage and later use. Lastly, parts of certain macrophytes, such as *Typha latifolia* and *Symphytum officipale* are edible. The rhizomes and young shoots of *Typha latifolia* can be cooked and eaten, whereas the leaves of *Symphytum officipale* can be used as a dressing against open wounds and burns.

5.4. Helophyte Filters in the Netherlands

In 1967 the first helophyte filter was constructed by the IJssel Lake Polder Authority (Rijksdienst IJsselmeer Polders, RIJP) in Flevoland. Although there was a lot of prejudice about odour nuisance, increase of flies and mosquitoes and poor removal efficiencies in the winter a FWS helophyte filter, with a depth of 0.4 m and surface area of 1 ha (5 m^2/p.e.), was constructed. This helophyte filter (with others being constructed as well) was used to treat the wastewater of isolated villages and recreational resorts after the last three polders in the former Zuiderzee (now IJsselmeer) were reclaimed (Jong, 1976; Veenstra (1998) as quoted in Vymazal and Kröpfelová, 2008; Vymazal *et al*., 2006; Vymazal and Kröpfelová, 2008).
The FWS helophyte filter had a star shape to use the available area most optimally. However, this posed a problem when mowing the macrophytes and hence channels were added. These allowed for better access for operational and maintenance procedures but also doubled the surface area of the helophyte filter. This helophyte filter removed the pollutants from the wastewater very well and at lower costs than conventional treatment at the time. During the 1970's approximately 20 FWS helophyte filters were in use in the Netherlands (Jong, 1976; Veenstra (1998) as quoted in Vymazal and Kröpfelová, 2008; Vymazal *et al*., 2006; Vymazal and Kröpfelová, 2008).

The FWS helophyte filters constructed over the next decade were mainly used to treat dairy farm wastewaters and surface water bodies in which the sewer system overflowed. H-SSF helophyte filters are seldom used in the Netherlands. They have been used to treat runoff water, industry wastewaters and some domestic or farm wastewaters. The V-SSF helophyte filters have seen an increase in implementation during the past two decades (Veenstra (1998) as quoted in Vymazal and Kröpfelová, 2008; Vymazal *et al*., 2006; Vymazal and Kröpfelová, 2008) as the V-SSF helophyte filter is the most efficient per unit of area in removing pollutants from wastewater. In addition, Dutch legislation prescribed the mandatory treatment of domestic wastewater before it is discharged to a surface water body in 2005 and the V-SSF helophyte filter has been given the certificate that allows it to be used for this purpose. Furthermore, a quality KIWA label assuring the use of quality construction material and good pollutant removal efficiencies was given to the V-SSF helophyte filter as well.

Next to treating domestic and (dairy) farm wastewater from settlements and farm in rural areas helophyte filters are also used to treat surface runoff from roads to remove heavy metals, polish the effluent of several wastewater treatment plants and polish surface water bodies (Bak *et al.*, no date). Especially the latter is a common use in the Netherlands.

Buildings and neighbourhoods being constructed with ecological and sustainable objectives sometimes also make use of helophyte filters constructed in their gardens to treat their wastewater. This is more from an ecological need than the necessity to safely discharge their wastewater as these buildings and neighbourhoods are also connected to the sewage system. This is mandatory by Dutch law.

The use of helophyte filters to treat wastewater at neighbourhood scale has been tried in several cases but failed due to poorly constructed houses (e.g. the Biezenlanden in Dordrecht; see the footnote on

[11] This study was used by the municipality of Groningen to motivate the decision to handle the clippings in Drielanden (Groningen, NL) as plant waste instead of chemical waste (see section 7.5.2).

page 4 as well) and poorly constructed helophyte filters. There probably are other reasons as well, but these are not always clear or properly documented. Helophyte filters are currently being used to treat wastewater at neighbourhood scale at three cases in the Netherlands (Drielanden (Groningen), Polderdrift (Arnhem) and Lanxmeer (Culemborg)). In all three cases only grey wastewater is treated; the black wastewater is fed into the local sewage system. These neighbourhoods were all constructed with ecological and sustainable objectives (see sections 7.1, 8.1 and 9.1).

5.5. Helophyte Filters in Developing Countries

The helophyte filters that are constructed in developing countries are mainly used to treat domestic wastewater before it is reused or discharged, industrial effluent from sectors such as the palm oil, coffee and paper industries to regulate environmental pollution as well as the treatment of water used in mining (Vymazal and Kröpfelová, 2008). The rate of implementation differs vastly per country, as some have full scale helophyte filters in operation to treat domestic wastewater and others are just in the experimental phases (Kivaisi, 2001).

Helophyte filters are considered a suitable technology for developing countries as they are regarded as cheap and easy to run and maintain as well as durable (Belmont *et al.*, 2004; Cooper, 2009; Dallas *et al.*, 2004; Denny, 1997; García *et al.*, 2005; Gross *et al.*, 2007; Kimwaga *et al.*, 2004; Kivaisi, 2001; Sperling, 1996). As they are a biological technology little outside input is perceived to be necessary for their functioning. However, Gopal (1999) mentions that the limiting factors for implementing helophyte filters in developing countries are the amount of land that is needed, the little knowledge about using helophyte filters in tropical climates, the construction and operational and maintenance costs and development programmes by western countries (Kivaisi, 2001). The latter is also recognised by Denny (1997) who states that technologies with commercial spin-off for the donor, as well as sophisticated state-of-the-art technologies, are most favoured in these programmes. Due to the little input needed once helophyte filters are operational (see sections 7.4, 8.4 and 9.4) there is little potential commercial spin-off, and neither do they have a sophisticated image.

Construction costs could be responsible for more than 50 per cent of the total budget for implementing and operating a helophyte filter. As this sum will need to be produced in a very short time period, opposed to the other half that can be spread over more than 20 years, there are other wastewater treatment technologies or management measures that could be preferred (Dallas *et al*., 2004; Denny, 1997). The treatment performance of a SSF helophyte filter is also reduced as it has the risk of clogging when no apt pre-treatment measures (such as a grease trap and septic tank) are installed (Caselles-Osorio and García, 2007; Stott *et al*., 2003). If this happens the whole bed will need to be rehabilitated thereby drastically increasing the costs for the local users of donor.

Vymazal and Kröpfelová (2008) mention in their book that all types of helophyte filter are being implemented in developing countries. Although the mentioned numbers are not huge (e.g. 30 in Southern Africa in 1990 with a relative slow increase in numbers since) a (slow) increase in implementation is seen (Denny, 1997; Vymazal and Kröpfelová, 2008). This low rate of implementation could be explained by the factors described previously. However, there seems to be a change of attitude in some in development programmes where terms such as stakeholder involvement, local capacity building and sustainability have become popular. These, with the desire to increase chances that a project will be successful in the long term in order to win more credibility, result in an increased rate of implementation. The warm and tropical climates in developing countries (resulting in higher biological activity), and the increase in knowledge about helophyte filters, as well as their implementation, in the Western countries could also be a basis for the increase in implementation of helophyte filters in developing countries.

6. Grey Wastewater Characteristics

6.1. Grey Wastewater from (Dutch) Households

In 2010 the total potable water consumption was 120 l/c/d (compared to 135 in 1992; 134 in 1995; 128 in 1998; 126 in 2001; 124 in 2004 and 128 in 2007). Twenty-eight per cent, or 34 l, was used to flush the toilets while the remaining 86 l/c/d was used in places that produce grey wastewater (Figure 8). Hence this figure, rounded up to 90 l/c/d, is often used when calculating the grey wastewater production in the Netherlands. The 72 per cent of the total domestic wastewater produced in the Netherlands is on the high end of the 60 to 75 per cent for west-European countries mentioned in literature (Elmitwalli and Otterpohl, 2007; Eriksson *et al*., 2002; Friedler, 2004; Hernández Leal *et al*., 2007; Jefferson *et al*., 1999; Li *et al*., 2009a).

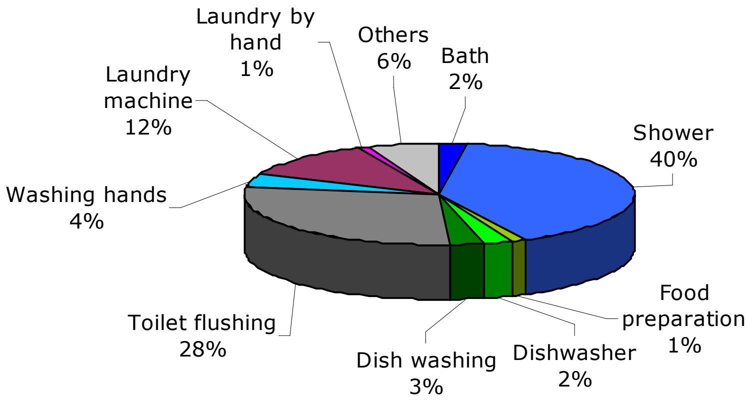


Figure 8. Average Dutch consumption of potable water in 2010, per use. *Note: total water consumption is 120.1 l/c/d* (Foekema and Thiel, 2011)

The largest part of the grey wastewater produced comes from the shower; 40 per cent or 49 l/c/d. This is an increase compared to 2001 when it was 42 l/c/d, but a decrease compared to 2007 (50 l/c/d). Foekema and Thiel (2011) ascribe it to people taking longer showers in 2010 than in 2001. However, the frequency of taking a shower has decreased and the use of a water saving shower head has increased (and hence the decrease in total water used for showering since 2007). The second largest grey wastewater producer is the laundry machine (12 per cent or 14 l/c/d). This figure was higher in 2001 (23 l/c/d). An explanation could be that people have bought new, more efficient and effective laundry machines. As more than half (56 per cent) of the grey wastewater comes from the shower and another 16.6 per cent comes from laundry machines, almost three-quarters of the grey wastewater is produced in a relatively short amount of time. This results in high peak flows at certain moments, as is also mentioned by Elmitwalli and Otterpohl (2007) and Imura *et al*., (1995), and a low grey wastewater production at other times of the day (Jefferson *et al*., 1999).

Part of the potable water consumed as 'Food preparation' or in 'Other' uses does not become grey wastewater as it will be evaporated by heating or disposed of via the toilet since it is consumed (Foekema *et al*., 2008). Besides this, water in the category 'Other' is probably also used for cleaning, meaning that the wastewater can be discarded of by means of the toilet, sink or infiltration outside (e.g. washing a car). Hence the 90 l/c/d is a rough indication.

Of all wastewater streams originating in a household, those coming from the toilet and kitchen are the most concentrated. Although the latter is small (Figure 8) it can be very concentrated with organics, pollutants and micro pollutants. The other streams, coming from the bathrooms, laundry activities, washing hands and preparing food and washing dishes are relatively diluted (Eriksson *et al*., 2002; Jefferson *et al*., 2004; Kujawa-Roeleveld, 2005; Li *et al*., 2009b). These diluted streams mix with the more concentrated kitchen wastewater. As a result Dutch grey wastewater is more diluted than domestic or black wastewater.

The characteristics of grey wastewater are influenced by multiple factors. The first is the composition of the supplied (potable) water. The second factor is the type and state of the water distribution and collection network as leakages and intrusion of other waters (such as wastewater from other sewage systems and groundwater) will influence the grey wastewater characteristics. Furthermore, chemical and biological processes taking place in the sewage pipelines and collection tanks, such as reactions between pollutants, the development of biofilms and the breakdown or growth of organic compounds and pathogens, will also have an influence (Eriksson *et al*., 2004). Dijk (2010), Dixon *et al*. (2000), Eriksson *et al.* (2002) and Jefferson *et al*. (1999; 2004) mention that if grey wastewater is stored BOD levels will drop, but after 24 hours TSS levels increased rapidly.
The third factor is the personal water-use habits and products used. The amount of water used per turn, as well as the amount of household product used or waste flushed will vary from time to time, resulting in a high variation of grey wastewater characteristics. Occupancy, geographical location and demography

also influence grey wastewater characteristics (Eriksson *et al.*, 2004; Hernández Leal *et al.*, 2007; Jefferson *et al.*, 1999; 2004; Li *et al.*, 2009b). Jefferson *et al.* (2004) did a study with two individuals who were asked to use the same types of soaps and shampoos, the same amounts of water and bath for the same amount of time (within reason), during the same time (one month). Grey wastewater samples taken from the shower and bath showed a 29 per cent and 17 per cent relative deviation in BOD_5 levels, respectively. This can be compared with 38 per cent and 44 per cent deviation, respectively, in their main sampling programme, which is considerable.

6.2. Household Sources of Characteristics

6.2.1. Physical

Although colour turbidity and electro-conductivity are also relevant grey wastewater characteristics, they are not discussed below as they are not in the scope of this research. More information on these characteristics can be found in studies by Eriksson et al. (2002), Friedler (2004), Jefferson et al. (1999; 2004) and Li et al (2009a; 2009b).

Total Suspended Solids (TSS) mainly come from laundry and kitchen wastewater in a relative concentrated form (70-470 mg/l and 230-720mg/l, resp.). These high concentrations are similar to domestic wastewater (Eriksson *et al.*, 2002; Li *et al.*, 2009b). Wastewaters from these sources can contain sand, clay, fabric particles and food wastes (including lipids). The shower and bath wastewater also contributes to the TSS-levels but this is in lower concentrations (30-120mg/l) (Eriksson *et al.*, 2002; Jefferson *et al.*, 2004; Friedler, 2004; Li *et al.*, 2009b). Nevertheless, the solids that do come from the shower and bath are generally relatively large (200-2000 µm) due to hairs, skin particles and lumps of soap (Jefferson *et al.*, 2004). Average TSS concentrations in grey wastewater range from 35 mg/l to 185 mg/l (Li *et al.*, 2009b).
Although the TSS-concentrations in grey wastewater are lower than in black wastewater, they do account for 55 to 70 per cent of the TSS concentrations in domestic wastewater (Eriksson *et al.*, 2002; Friedler, 2004).

In general *temperatures* of grey wastewater range from 12 ºC to 20 ºC, but they can be as low as 7.5 ºC and as high as 38 ºC, depending on the source, measurement point and time period in which the measurements were taken (Dijk, 2000; Eriksson *et al.*, 2002; Hernández Leal *et al.*, 2007;). The high temperatures are due to the use of warm water for personal hygiene as well as household appliances such as dishwashers and laundry machines. Not only do higher wastewater temperatures favour microbiological growth, but it can also lead to the precipitation of Calcium Carbonate ($CaCO_3$) as some salts become less soluble at higher temperatures (Eriksson *et al.*, 2002).

6.2.2. Chemical

The *pH* of grey wastewater generally ranges from 6.4 to 8.1 (Li *et al.*, 2009b). Grey wastewater originating in laundry is usually more alkaline and has a pH of 8-10 due to the chemical products used. The pH mainly depends on the characteristics of the water supplied to the household and is hence quite neutral (Eriksson *et al.*, 2002).

Measurements of the *Biological Oxygen Demand* (BOD) over a 5 day period (BOD_5) show that levels in grey wastewater range from 40 to 460 mg/l (Eriksson *et al.*, 2002; Li *et al.*, 2009a; 2009b). This is a bit lower than levels recorded in municipal wastewater (150-530 mg/l) (Eriksson *et al.*, 2002). Kitchen wastewater is the main contributor of BOD_5 in grey wastewater, with ranges of 5 to 1460 mg/l being recorded. Laundry and bathroom levels range from 40 mg/l to 480 mg/l and 70 mg/l to 300 mg/l, respectively (Eriksson *et al.*, 2002).

Chemical Oxygen Demand (COD) levels range from 100 mg/l to 590 mg/l in grey wastewater (Eriksson *et al.*, 2002; Jefferson *et al.*, 2004; Li *et al.*, 2009a; 2009b). These concentrations are a bit lower than those found in domestic wastewater (210-710 mg/l) as the main source of COD in this wastewater comes from laundry and kitchen wastewater (Eriksson *et al.*, 2002; Jefferson *et al.*, 2004). COD concentrations in laundry wastewater range from 725 mg/l to 1815 mg/l, and in kitchen wastewater from 26 mg/l to 1380 mg/l, depending on the activity taking place. Dishwasher and laundry detergents are the main source for high COD levels in kitchen wastewater (Eriksson *et al.*, 2002; Hernández Leal *et al.*, 2007; Jefferson *et al.*, 2004). Wastewater from the bathroom has lowest COD concentrations: 100 mg/l to 633 mg/l (Eriksson *et al.*, 2002).

6.2.3. Pollutants

As urine is the main source of *Nitrogen* (N) concentrations in household wastewater, it is present in relatively low concentrations in grey wastewater (0.6-74 mg/l versus 20-80 mg/l for household wastewater) (Jefferson *et al.*, 2004; Kujawa-Roeleveld, 2005; Li *et al.*, 2009b). The main source of N in grey wastewater comes from soaps and detergents used in the kitchen (40-74 mg/l) (Eriksson *et al.*, 2002; Li *et al*., 2009b). Inhabitants urinating in showers and baths also contribute to N concentrations in grey wastewater although this is thought to be minimal.

Since several countries, such as Italy, Germany and the Netherlands, had prohibited or discouraged the use of *Phosphorus* (P) in laundry detergents in the 1960's and 19 70's, P-levels in grey wastewaters have decreased from 6-23 mg/l to 4-14 mg/l (Eriksson *et al.*, 2002; Jefferson *et al*., 2004). P is a natural component in food as well as food additives and preservatives. In kitchen wastewater P mainly comes from dishwashing detergents (SenterNovem, 2008; Friedler, 2004; Kujawa-Roeleveld, 2005; Li *et al*., 2009a).

6.2.4. Micro pollutants

Other pollutants in grey wastewater are *heavy metals* (e.g. Al, Fe, Mn, Cd, Cu, Pb, Hg, Zn, Ni, and Cr), *salts*, *micro organic compounds*, *xenobiotic compounds* and *medicine residues* (Eriksson *et al.*, 2004; Friedler, 2004; Gross *et al.*, 2005; Kujawa-Roeleveld, 2005). The concentrations that these occur in are considerably higher in grey wastewater than in household wastewater due to the chemicals (detergents, soaps, shampoos, perfumes, preservatives, dyes, cleaners) used in households, dust collected during cleaning activities and medicines used (Eriksson *et al.*, 2004; Friedler, 2004; Gross *et al.*, 2005; Kujawa-Roeleveld, 2005). Heavy metals can also originate in kitchen water due to food wastes. However, this will be in very low concentrations (Kujawa-Roeleveld, 2005).

In general, the above figures conclude that grey wastewater, coming from Western Europe households, can be categorized as medium strength wastewater (see section 6.3) (Jefferson *et al*., 2004; Li *et al*., 2009b).

6.2.5. Microorganisms

Microorganisms, including pathogens, are present in grey wastewater. Although their concentrations are much lower than those found in black wastewater (10^3-10^5 cfu/100ml vs. 10^5-10^8 cfu/100ml) (Gross *et al*., 2007; Metcalf and Eddy, 2004; Ottoson and Stenström, 2003; WHO, 2006) they are significant enough to prohibit unrestricted use of untreated grey wastewater (WHO guideline value of $<1x10^3$ cfu/100 ml). The main sources of pathogens are bath and shower wastewater, laundry wastewater and kitchen wastewater. As there are many different types of microorganisms and different analyses required to find these one cannot simply speak of one concentration. Instead, certain pathogens such as faecal enterococci, faecal coliforms or enteric viruses are often used as indicators of contamination severity and thus the risk to one's health. However, correlations between the actual concentrations and the concentrations of the indicator organism are not always as clear (Asano (1998) as quoted in Jefferson *et al*., 1999; EPA, 2002; Jefferson *et al.*, 1999; Roesner *et al*., 2006; Ottoson and Stenström, 2003).
In general, faecal coliforms are measured most often as they are relatively easy to detect. A critical side note here is that this is not always accurate. Literature differs on how accurate it is as Jefferson *et al.*, (1999) states that it leads to underestimation, whereas Ottoson and Stenström (2003) found the exact opposite. As *E.coli* is the only pathogen that is found exclusively in faeces and does not multiply well outside the gastronomic track it is often used as an indicator for faecal coliforms (Metcalf and Eddy, 2004; Paruch, 2011).

Rose *et al.* (1991) and Casanova *et al*. (2001) found that bath and shower wastewater has higher concentrations of pathogens than laundry wastewater, except when nappies are being washed. They also discovered that households with small children had significant higher coliform concentrations in grey wastewater than households with no children ($3.2x10^5$-$4.99x10^5$ cfu/100 ml vs. 6-80 cfu/100 ml). Microorganisms in kitchen wastewater come from the (manual or mechanical) washing of kitchen utensils, dishes and hands that have been in contact with foods such as vegetables, meats and eggs. These can contain faecal coliforms, bacteria, viruses and helminth eggs (Casanova *et al*., 2001; Rose *et al*., 1991).

During storage the influence of phosphates, ammonia and pollutants present in grey wastewater is positive on microorganism growth, indicating that grey wastewater should not be stored too long (Dixon *et al*., 2000; Rose *et al*., 1991).[12]

6.3. Dutch Grey Wastewater Characteristics

A comparison of Table 6 and Table 7 shows that based on concentrations found in literature, in general Dutch grey wastewater can be classified as medium strength wastewater. This corresponds with literature on Western Europe grey wastewater characteristics (See section 6.4; Metcalf and Eddy, 2004; Jefferson *et al*., 2004; Li *et al*., 2009b). The BOD_5 and COD concentrations measured in Lanxmeer by

[12] As bath and shower wastewater contains the highest pathogenic concentrations Dixon *et al.* (1999) and Roesner *et al*. (2006) wonder if sitting in a bath poses a higher risk to ones health than flushing the toilet with treated grey wastewater, which is an issue often debated. They, unfortunately, do not give a clear answer on this but it is good food for thought.

Vitens nv are an exception. These quite low, but this is attributed to the absence of kitchen wastewater (SenterNovem, 2008).

Table 6. Pollutant concentrations in different wastewater strengths (Metcalf and Eddy, 2004)

	Units	Concentration in wastewater		
		Low	**Medium**	**High**
BOD_5	mg/l	110	190	350
COD	mg/l	250	430	800
N-total	mg/l	20	40	70
TKN	mg/l	20	40	70
NO_3^-	mg/l	0	0	0
NO_2^-	mg/l	0	0	0
NH_4^+ / NH_3	mg/l	12	25	45
P-total	mg/l	4	7	12
TSS	mg/l	120	210	400
O_2	mg/l	---	---	---
pH	-	---	---	---
Temp.	ºC	4-35	4-35	4-35
E.coli	cfu/100ml	10^3-10^5	10^4-10^6	10^5-10^8

The high COD, N and P concentrations found by Hernández Leal *et al*. (2007) in Sneek (Table 7) was explained by the timing of the sample collection. This was done when inhabitants were doing their laundry. The two other cases from Sneek (Hernández Leal, 2010; Zeeman *et al.*, 2008) have much lower COD, N and P concentrations. The COD pollutant loads of these latter two cases (43.5-50.8 gr/c/d and 37.7-43.9 gr/c/d, respectively) are 40 to 50 per cent lower than the COD loads recorded by Hernández Leal *et al*. (2007). They are similar to those recorded by the same authors in Groningen (37.3 gr/c/d). The COD loads recorded in Groningen by Dijk (2000) are higher (54.3 gr/c/d) and can be attributed to the relative high water consumption. COD loads mentioned in STOWA literature (Kujawa-Roeleveld, 2005; Wijst and Groot-Marcus, 1998) (53.7 gr/c/d and 52 gr/c/d, respectively) are similar to the higher loads recorded in Sneek and Groningen. The values given in the column under 'Deugd' are used in a design for a grey wastewater treatment technology by Tauw bv, Deventer (Telkamp, 2010). The calculated COD load here was 47.3 gr/c/d, which was well within the earlier mentioned ranges.

N-total loads (not concentrations!) are similar for all cases, except for the one from Sneek mentioned by Hernández Leal *et al*. (2007) that has high COD concentrations as well. And the concentrations measured in Lanxmeer, which are on the low end. Interestingly, NH_4^+ loads are lower in Sneek (again, except for the one mentioned by Hernández Leal *et al*. (2007)) than in Groningen. Those mentioned in STOWA literature and used in the DEUGD project are similar to the loads found in Groningen. P-total concentrations are similar for all cases, except for one. This is not the one from Hernández Leal *et al*. (2007) but a case in Groningen (Dijk, 2000). Here the P-total load is very low for reasons not known.

The measured *E.coli* concentrations in Lanxmeer are very low. This was expected as *E.coli* originates in the gastronomic tracks of humans and as grey wastewater generally contains no faeces high *E.coli* concentrations are not expected.

Although there is a range in the COD loads the actual concentrations clearly differ per location. Sneek has consistently higher concentrations than Groningen. COD concentrations used for the design of the DEUGD project as well as those provided by STOWA for general designs are lower than those from Sneek but higher than those from Groningen. As the earlier calculations have shown the COD loads are comparable (within a range), leading to the conclusion that when inhabitants produce less wastewater the COD pollutant load will not lessen. This will result in a smaller but more concentrated wastewater stream. However, the same conclusion cannot be drawn as straight forward for the N-total, P-total and NH_4^+ concentrations. This, with the high standard deviations (grey figures) that all values have implies that grey wastewater characteristics are not as straightforward as one would initially think. Instead, there are differences per location and time.

Table 7. Dutch grey wastewater characteristics found in literature[13, 14]

	Units	Groningen[1, 4; A]	Groningen[2, 3; B]	Lanxmeer[5; C]	Sneek[1; D]	Sneek[4; E]	Sneek[6; F]	Sneek[7]	DEUGD[8; G]	STOWA 1998-40[9; H]	STOWA 2005-14[10; I]
# of houses	-	110	110		32	32	32	32			
n		104	17	7	10	[J]	10				
Water consumption	l/c/d	90	98.8	---	60-70	60-70	60-70	---	90	95.1	91.3
BOD_5	mg/l	215	298	116	---	---	---	---	263	---	285-307
std	*mg/l*	± 102.4		47							
COD	mg/l	425	550	267	1583	725	627.5	833	526	564.4	570
std	*mg/l*	± 107.3		61	± 382	± 150	± 139.6	± 188			
N-total	mg/l	17.2	---	11.0	47.78	26.3	19.36	41.2	18.3	---	11-15
std	*mg/l*	4.7			± 27.06	± 12	± 4.82	± 27.2			
TKN	mg/l	---	12.6	10.0	---	---	---	---	---	4.43	---
std	*mg/l*			1.7							
NH_4^+	mg/l	7.25	4.9	6.8	16.35	2.7	4.16	1	5.7	---	---
std	*mg/l*	± 3.68		1.8	± 6.78	± 2	± 0.96	± 0.7			
P-total	mg/l	5.73	1.8	4.5	9.86	7.5	4.95	6.6	5.3	---	3-5
std	*mg/l*	± 2.64		0.5	± 9.86	± 4.2	± 1.62	± 2.7			
TSS	mg/l	---	64	---	---	---	---	---	---	---	---
std	*mg/l*										
O_2	mg/l	8.9	2.3	---	---	---	---	---	---	---	---
std	*mg/l*										
pH	-	7.12	7.08	7.4	---	---	---	---	7-7.5	---	---
std	-			0.1							
Temp.	ºC	16.5	12.08	---	---	---	---	---	25	---	---
std	*ºC*		± 3.9								
E.coli	cfu/100ml	---	---	>300->600	---	---	---	---	---	---	---

Sources:
1: Hernández Leal *et al.*, 2007
2: Dijk, 2000
3: Mels *et al.*, 2005a
4: Hernández Leal, 2010, Ch. 2
5: SenterNovem, 2008
6: Zeeman *et al.*, 2008
7: Hernández Leal, 2010, Ch. 3
8: Telkamp, 2010
9: Wijst and Groot-Marcus, 1998
10: Kujawa-Roeleveld, 2005

Notes:
A: 18-32 Oct. 2005, every 1.5 hr.
B: Averages of monthly samples. Converted from mg/l-N to mg/l
C: 21-27 Sept. 2007, daily composite samples. No kitchen wastewater. Location in Lanxmeer is unknown.
D: Jul.-Nov. 2006, only in the morning
E: 14 months
F: Jul.-Nov. 2006, only in the morning
G: Literature for NL (desk study by Telkamp)
H: Calculations based on figures found in Wijst and Groot-Marcus (1998) and general factors assumed at Dutch wastewater treatment plants (Telkamp, 2010)
I: Derived from gr/c/d
J: *n* = 182, 156, 158, 119 resp.

[13] Although data under 'DEUGD' and 'STOWA' are not from an actual location they are mentioned here, because they are presented and used in Dutch literature as general grey wastewater values. These are also used when designing grey wastewater treatment technologies.
[14] Values in the second column under 'DEUGD' are used for designing grey wastewater treatment systems at Tauw Deventer.

6.4. European Grey Wastewater Characteristics

Table 8 shows grey wastewater characteristics from cases in Europe as found in literature. Four cases are from Germany (Elmitwalli and Otterpohl, 2007; Hernández Leal, 2010; Li *et al.*, 2003; Li *et al.*, 2009; Mels *et al.*, 2005a), one from Sweden (Hernández Leal, 2010; Palmquist and Hanaeus, 2005), one from the UK (Jefferson *et al.*, 2004) and the remaining two columns show the results of two literature reviews (Eriksson *et al.*, 2002; Li *et al.*, 2009b).[15]

As can be seen in Table 8 each pollutant concentration has a certain range. However, within this range there is a relative high variance for all pollutants as the large standard deviations or ranges show. The ranges are larger than those of the pollutants found in Dutch grey wastewater. Especially P-total concentrations can be much higher. This can be ascribed to Dutch legislation prohibiting the use of P in laundry detergents, which might not be the case in other countries.

When compared to Table 6 the grey wastewater from the cases in Europe can overall be described as medium strength wastewater, although there are several cases where its strength is high. These high concentrations are only recorded in the literature reviews and come from cases where water can be scarce such as Israel (Li *et al.*, 2009b) or Australia (Eriksson *et al.*, 2002). As was shown in the previous section, certain pollutants can become more concentrated when less water is consumed.

E.coli concentrations present in the grey wastewater shown are similar to those found in the low and medium strength wastewaters, but much higher than those recorded in the grey wastewater from Lanxmeer.

When comparing Dutch grey wastewater characteristics (Table 7) with mainly European grey wastewater characteristics (Table 8) found in literature the BOD_5, COD, P-total, TSS, pH and temperature values were found to be similar. In the Dutch grey wastewater the N-total and NH_4^+ concentrations are on the high end compared to the European concentrations, whereas the dissolved oxygen concentrations were lower. However, in the Dutch case there was only one measurement of the latter thereby lessening its credibility. It is unknown why N-total and NH_4^+ concentrations are higher in Dutch wastewater. As urine is the main source of N in domestic wastewater a possible explanation could be that Dutch people urinate more when taking a shower or bath compared to other Europeans, but this has not been validated with a study. No information on *E.coli* concentrations in Dutch grey wastewater has been found, and hence no comparison can be made.

6.5. International Grey Wastewater Characteristics

Table 9 shows grey wastewater characteristics collected from literature studying different international cases. The grey wastewater characteristics shown come from cases in Israel (Gross *et al.*, 2005; Gross *et al.*, 2007) and Jordan (Abu-Ghunmi, 2009; Abu Ghunmi *et al.*, 2008; Abu Ghunmi *et al.*, 2010a; Halalsheh *et al.*, 2008; Jamrah *et al.*, 2006; Suleiman *et al.* (2006) in Abu Ghunmi, 2009; Zeeman *et al.*, 2008), where its treatability and reuse potential was assessed. The case from Costa Rica (Dallas and Ho, 2005) explored the suitability of an alternate medium (PET bottles instead of expensive gravel) for SSF helophyte filters treating domestic and grey wastewater in rural areas. The grey wastewater characteristics from Nepal (Shrestha *et al.*, 2001b) originate from research on the use of helophyte filters to treat domestic, grey and hospital wastewater in order to protect surface water bodies.

Using Table 6 the cases can be classified according to the grey wastewater strength. These range from very low (Abu-Ghunmi, 2009; Jamrah *et al.*, 2006) to very high (Halalsheh *et al.*, 2008; Suleiman *et al.* (2006) in Abu Ghunmi, 2009). Nevertheless, most of the cases are in the medium to high strength range with the weakest being Nepal and most concentrated being from Israel.

The striking difference with Table 7 and Table 8 is that the grey wastewater concentrations in Table 9 have a high variance. This high variance originates from two different cases in Jordan. The low concentrations come from grey wastewater in which no kitchen or laundry wastewater is included as the wastewater of these actions flowed somewhere else (Abu-Ghunmi, 2009; Jamrah *et al.*, 2006), whereas the high concentrations come from rural households that use very little water (14±3 l/c/d) (Halalsheh *et al.*, 2008; Suleiman *et al.* (2006) in Abu Ghunmi, 2009).

[15] These literature reviews show grey wastewater characteristics from mainly European countries but also include certain studies from North America, Israel en Australia. As it is not always clear which grey wastewater characteristics relate to which region, the values are included in this Table and not in Table 9, where grey wastewater characteristics of other countries are shown. If the grey wastewater characteristics could be retraced to a certain article, as was the case with Gross *et al*. (2005) and Gross *et al.* (2007), who were mentioned by the literature review of Li *et al*. (2009b), the grey wastewater characteristics mentioned by these authors are shown in Table 9 and not included in Table 8 .

Table 8. European grey wastewater characteristics found in literature

	Units	Lübeck[1; A]	Lübeck[2, 3; A, B]	Lübeck[4; C]	Germany[5; D]	Vibyåsen[2, 6; E]	UK[7; F]	Literature[8; G]	Literature[9; H]
# of houses	-		111	111		32	32		
n			6			10			
Water consumption	l/c/d	---	---	70	---	60-70	---	90	91.3
BOD_5	mg/l	194	---	---	47-166	---	146	50-350	119-360
std	*mg/l*						± 54.3		
COD	mg/l	502	640	258-354	100-700	588	451	100-681	13-549
std	*mg/l*		± 127				± 289		
N-total	mg/l	12	---	9.7-16.6	1.7-34.3	9.68	5	3.72-53.6	0.6-18.1
std	*mg/l*								
TKN	mg/l	---	27.2	---	---	---	---	---	2.1-31.5
std	*mg/l*		± 3.5						
NH_4^+	mg/l	5.8	5.4	---	---	---	---	---	<0.05-25.4
std	*mg/l*		± 2.6						
P-total	mg/l	8	9.8	5.2-9.6	0.11-22.8	7.53	1.37	0.7-22.8	0.6-27.3
std	*mg/l*		± 0						
TSS	mg/l	---	---	---	25-183	---	100	35.09-185	17-330
std	*mg/l*						± 145		
O_2	mg/l	---	---	---	---	---	---	---	0.4-5.8
std	*mg/l*								
pH	-			6.9-8.1	6.3-8.1	7.5	7.47	6.4-8.1	5-8.7
std	-						± 0.29		
Temp.	ºC	---	---	---	---	---	---	---	18-38
std	*ºC*								
E.coli	cfu/100ml	---	---	$7.5x10^3$-$2.5x10^5$	---	---	$2.022 x10^3$	---	<1-$2.4x10^4$

Sources:
1: Mels *et al.*, 2005a
2: Hernández Leal, 2010, Ch. 2
3: Elmitwalli and Otterpohl, 2007
4: Li *et al.*, 2003
5: Li *et al.*, 2009a
6: Palmquist and Hanaeus, 2005
7: Jefferson *et al.*, 2004
8: Li *et al.*, 2009b
9: Eriksson *et al.*, 2002

Notes:
A: Converted from mg/l-N to mg/l
B: Representable for 1 day
C: Nov. 2000-Feb. 2001
D: Summarisation of PhD data
E: A mixed 3 hr. sample
F: No Laundry
G: summarisation of literature
H: summarisation of literature

When converted from concentration to load, the COD load of the latter case is 35.9 gr/c/d which is comparable to the other Jordanian cases (36.4 gr/c/d and 17.2-24.5 gr/c/d, respectively) as well as the Dutch cases. The COD load is the highest in Israeli grey wastewater (133.9 gr/c/d). Although the COD concentrations measured at this case are not extremely high a lot of grey wastewater is produced (195.2 l/c/d) and hence the COD load produced is high. The COD load measured in Nepal is 14.2 gr/c/d, which is low compared to the Dutch cases.

Interestingly, N-total loads are highest in grey wastewater from Israel (Gross *et al.*, 2005) due to the high water consumption. The N-total load is 2.7 gr/c/d versus about 0.5 gr/c/d for the other cases. The TKN load of the grey wastewater mentioned by Halalsheh *et al*. (2008) and Suleiman *et al*. (2006) in Abu Ghunmi (2009) is 1.8 gr/c/d. This, with the high NH_4^+ load of 1.1 gr/c/d can be explained by the fact that nappies and small children are often washed in the sinks. The high TSS load (15 gr/c/d) also supports this.
P-total loads in most cases are similar (around 0.5 gr/c/d) and comparable to the Dutch figures, except one from Israel (Gross *et al.*, 2005) where it is 3.5 gr/c/d. The TSS load in this grey wastewater is also high (26.9 gr/c/d), which could be a result of the increased laundry and kitchen wastewater stream (see comment 'B' below Table 9).

The pH ranges are larger than those in Dutch grey wastewaters, which can be explained by the varying concentrations as well as different product composition and use. Temperature values are also higher. This could be explained by the warmer climates in which the different cases exist and hence less cooling down of wastewater.

High *E.coli* concentrations in the rural Jordanian wastewater (Halalsheh *et al*., 2008; Suleiman *et al*. (2006) in Abu Ghunmi, 2009) are due to the nappy rinsing and perhaps measurements in summer, when warmer temperatures can also stimulate pathogenic growth (see section 6.2.5). The high *E.coli* concentration in grey wastewater originating in the female dormitories during the summer (Abu Ghunmi *et al*., 2010a) is not explained in the literature. It could not be compared to *E.coli* concentrations in grey wastewater from the same dorm during a winter period as this wastewater was not analysed for *E.coli* (Abu Ghunmi *et al.*, 2008).

There are several conclusions that can be drawn from the last overview of grey wastewater characteristics found in literature. Water consumption differs vastly per case. A dry country does not imply that less water is consumed, as one of the Israeli cases showed. There is also a large difference between cases from the same country, such as Jordan. Nevertheless, poorer and dryer regions usually produce lower amounts of (grey) wastewater (Halalsheh *et al*., 2008; Li *et al*., 2009a; Suleiman *et al*. (2006) in Abu Ghunmi, 2009). If this phenomenon occurs most of the pollutant concentrations will increase. However, some pollutant concentrations in the small grey wastewater flows, such as P-total, were no different from the concentrations found in large grey wastewater flows, meaning that this statement cannot be generalised. Furthermore, an increase in pollutant concentration does not imply that the actual pollutant loads increases. Instead, in poor areas certain loads could even be lower due to small measures at which certain products are used.

These findings emphasize the importance of analysing individual wastewater streams in developing countries, as well as those from the west, as there is a large variance in amounts and different concentrations. Designs based on assumptions could very well miss the mark.

Table 9. International grey wastewater characteristics found in literature

	Units	Israel[1; A]	Israel[2; B]	Jordan[3; C]	Jordan[4; D]	Jordan[5]	Jordan[6, 7; E]	Jordan[8, 9; F]	Costa Rica[10; G]	Nepal[11; H]
# of houses	-		1	1	1		6	233		1
n		6	18	[I]		[J]	14	15	14	[K]
Water consumption	l/c/d	---	195.2	66±9	47-67	---	14±3	59	---	71
BOD_5	mg/l	466	270	149	150	122	1056	41	254	200.1
std	*mg/l*	± 66	± 60	± 46	± 31	± 26			± 84	± 93.6
COD	mg/l	839	686	551	366	548	2568	78	---	411.4
std	*mg/l*	± 47	± 255	± 202	± 165	± 86				± 174
N-total	mg/l	34.3	14	10	12.0	7.9	---	9.2	<1	---
std	*mg/l*	± 2.6	± 2	± 14	± 0.6	± 5.2				
TKN	mg/l	---	---	---	---	---	128	---	---	---
std	*mg/l*									
NH_4^+	mg/l	0.3	---	8	---	6.4	75	---	---	13.3
std	*mg/l*	± 0.1		± 6		± 2.9				8
P-total	mg/l	22.8	17.7	7	11	17.8	19.5	9	9.6	
std	*mg/l*	± 1.8	± 5.1	± 7	± 8	± 7.0			± 6.0	
TSS	mg/l	158	138	122	169	---	1074	168	---	97.9
std	*mg/l*	± 30	± 21	± 78	± 60					± 53.4
O_2	mg/l	---	---	---	---	---	---	---	---	---
std	*mg/l*									
pH	-	6.3-7.0	6.7	7.6	---	---	6.35	7.81	5.2	---
std	*-*		± 0.1	± 0.2					± 0.5	
Temp.	ºC	---	---	24	20-36	---	---	---	22.1	---
std	*ºC*			± 5					± 2.2	
E.coli	cfu/100ml	---	---	---	1.4×10^6	---	2.0×10^5	---	---	---

Sources:
1: Gross *et al.*, 2007
2: Gross *et al.*, 2005
3: Abu Ghunmi *et al.*, 2008
4: Abu Ghunmi *et al.*, 2010a
5: Zeeman *et al.*, 2008
6: Suleiman *et al.*, 2006 in Abu Ghunmi, 2009
7: Halalsheh *et al.*, 2008
8: Jamrah *et al.*, 2006
9: Abu-Ghunmi, 2009
10: Dallas and Ho, 2005
11: Shrestha *et al.*, 2001b

Notes:
A: March-May 2002
B: 6 pers. farm with kitchen and laundry facilities for guesthouse
C: Female dormitory of 150 students. In winter
D: Campus of 150 students. In summer. Students and cleaners were aware of research
E: Rural Eastern Jordan, nappy rinsing and washing babies in sinks occurred. March-May 2005
F: No kitchen and laundry wastewater included, in Amman
G: Municipal domestic grey wastewater, Monteverde, Costa Rica
H: Household of 7, April 1998-May 2000
I: *n*=20, 96, 20, 20, 20, 26. 96 resp.
J: *n*=20, 10, 15, 15, 10 resp.
K: *n*= 9, 9, 9, 8 resp.

Part C. Case Descriptions

7. Drielanden

As explained earlier, the construction and development, technology and general functioning of three Dutch cases where helophyte filters treat grey wastewater at neighbourhood scale were analysed. These cases are Drielanden (Groningen), Polderdrift (Arnhem) and Lanxmeer (Culemborg). Their locations in the Netherlands are shown in Figure 9. In the next three chapters each case is described.

Figure 9. Location of the three cases analysed in this thesis (Google Earth)

The neighbourhood Drielanden is located in the north-east of the city of Groningen (Figure 10). It consists of three sub-neighbourhoods, namely Waterland in the west, Zonland in the middle and Mooiland on the eastern side, with a total of approximately 450 houses.

There are two FWS helophyte filters treating the grey wastewater of Waterland only (Figure 11). Zonland and Mooiland are connected to the conventional sewage system. There are 114 houses in Waterland. In the Netherlands the average number of p.e.'s per house is 2.4, making the total number of p.e.'s 274.

7.1. History

In 1989 the Association Ecological Living Groningen (Vereniging Ecologisch Wonen Groningen; VEWG) was established by group of people with the aim to realise a neighbourhood in which the construction, living environment and future demolition would have minimal impact on the environment. Energy, resources and water would be used in an efficient way, as well as having a lot of urban green, space for animals and children to play. This would mean that it would be a car-free neighbourhood (Dijk, 2010).

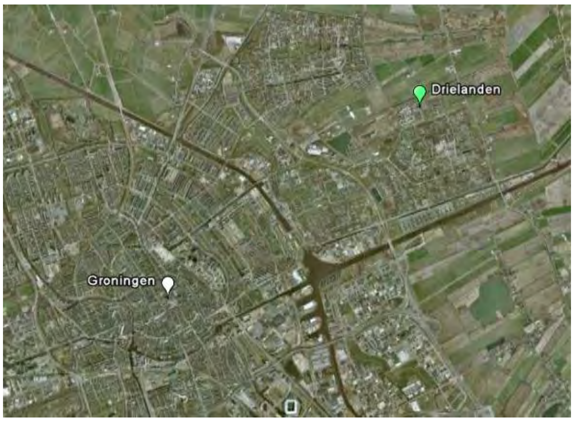


Figure 10. Location of Drielanden in Groningen (Google Earth)

The association approached the municipality of Groningen, the local Housing Corporation and architect Jan Giezen with these ideas. It was decided to go ahead with the project and in 1991 a presentation and meeting was organised. Several hundred people who were interested in these ideas came to this meeting, proving that there was enough enthusiasm. A period of meetings, ideas, designs, discarding of ideas, disappointments and enthusiasm finally led to a feasibility study for a project at Waterland. Plans and construction criteria were drawn up after which a construction team finalised everything (Dijk, 2010).

It soon became clear that not all plans could be executed due to the high costs. The VEWG wanted to sell the houses themselves to save 10 per cent of these costs to allow for more environmentally friendly adaptations to the houses, but the municipality did not agree with this (even though 60 per cent of the houses were already sold). Thus the prices increased with another 10% after a real estate agent was hired. The result was that solar collectors and composting toilets were not implemented. A second piping system for low quality household water also not constructed as the company providing water to the neighbourhood refused to support this plan. In order to make the neighbourhood more attractive for potential buyers the idea of a car-free neighbourhood was abandoned, resulting in less urban green (Dijk, 2010).

Later on in the project Zonland and Mooiland were added to the neighbourhood to make it financially more feasible. Of the three, Waterland is the most environmentally conscious and sustainable (Dijk, 2010). Hence the first inhabitants of this neighbourhood had relative ideals concerning environmental consciousness but in general the inhabitants are not much different than in any other Dutch neighbourhood. This could be due to the other two parts of the neighbourhood, Zonland and Mooiland as these are constructed in the more conventional way. In general there are families living in the houses, of which the composition differs. Overall, the household composition is average (Dijk, 2010).

The first houses were finished in 1995 and were, compared to the standards of the time, environmentally friendly, insulated very well, fitted with water-saving measures (i.e. Gustavsberg toilets) and mostly oriented towards the sun (Dijk, 2010).

Initially the helophyte filters had to treat the black wastewater but this idea was later dropped due to public health concerns (Dijk, 2010). They were finally constructed to treat the grey wastewater of Waterland, as well as to increase the quality of the surface water in Drielanden. The helophyte filters were finished in 1995 and taken in use in 1996 after the macrophytes had rooted (Dijk, 2010). Since then there have been several alterations to the design, including the demolition of a V-SSF helophyte filter, the construction of a concrete cascade and an inspection hole in the feedback-loop of effluent from the first FWS helophyte filter (Dijk, 2000; 2010; Jager, 2010).

7.2. Technology

The helophyte filters in Drielanden, Groningen are of the FWS type. Both have a horizontal surface flow direction. The first helophyte filter treats the grey wastewater coming from Waterland. The effluent is mixed with water from the surface water body nearby after which it is pumped to the second helophyte filter. From here the effluent is discharged to the neighbouring surface water body.
In Waterland there are 114 houses of which 26 are rented, the remaining are privately owned. Approximately 10 per cent of the produced grey wastewater is used to flush the black wastewater through the sewage pipes to prevent blockages. The remaining grey wastewater, about 25 m^3/d, is collected in a collection tank from where it is fed into the first helophyte filter.

Figure 11. FWS helophyte filters constructed in Drielanden, Groningen (Google Earth; Dijk, 2000)

The grey wastewater flows into the first (western) helophyte filter via a cascade to increase the oxygen content of the water. At the beginning of the first helophyte filter the influent is mixed with equal portions of the effluent and surface water to increase the oxygen concentration of the influent, dilute the concentration of pollutants and introduce bacteria that the effluent has collected while in the reed bed. After a retention time of 18 days the effluent is mixed with surface water (ratio 1:7) and flows to the second (eastern) helophyte filter where it is treated again. Here the retention time is 2 days. The effluent of this helophyte filter is discharged into the surface water body on the eastern side of the reed bed (Dijk, 2010).

Each helophyte filter has a surface area of 3000m^2, making the total surface of the helophyte filters 6000m^2.[16] The water depth in each filter is 0.3 m. The lining is a 0.3 m thick layer of compacted clay. As the whole area is constructed on clay soils leakage is not considered an issue (Dijk, 2010; Jager, 2010). There is no grease trap in the system. Sludge was never removed from the bottom of the helophyte filter, as during the research of Dijk (2000) the accumulation of sludge on the bottom was minimal (a few centimetres after 5 years of functioning) (Dijk, 2010). It should be noted that the helophyte filter has been over-designed due to the unfamiliarity with treating grey wastewater by means of a helophyte filter at that time. It is not known by how much this was (Dijk, 2000, 2010).[17]

The FWS helophyte filters are not used in the winter months (usually from November till April). This decision is based on the assumption that the biological activity of the bacteria and macrophytes decreases when the water temperature drops below 10 degrees Celsius. As a result it is thought that the pollutants will not be removed from the grey wastewater adequately. The grey wastewater is then diverted into the sewage system (Dijk, 2010). When the macrophytes start to grow again the grey wastewater is fed back into the helophyte filters. The exact times of stopping and starting the inflow of grey wastewater are decided upon every year as they depend on local conditions (Jager, 2010; Klopman, 2010).

[16] The total area per pollutant equivalent is 6000/(114x2.4)= 22 m^2/p.e..
[17] The design criteria were not found during this research.

Since its completion in 1996 several alternations to the original design have been made. Originally part of the grey wastewater was treated by a V-SSF helophyte filter. However, as the medium for this helophyte filter was loamy soil it soon started to clog and filter flooded. The grey wastewater was then able to back flow into the tank from which it was pumped. Furthermore, in the first year of its functioning there was a rapid decrease in oxygen concentrations in the effluent which resulted in a lot of odour nuisance. These two developments, with its higher demand for maintenance, led to the demolition of the V-SSF and the construction of a concrete cascade with blast-furnace slag at the beginning of the first FWS helophyte filter. This would allow for more bacterial growth and eddies that could result in higher oxygen concentrations in the influent (Dijk, 2000; 2010).
The municipality constructed an inspection hole in the pipe that transports part of the effluent of the first FWS helophyte filter to its influent. This was done to make sure that the effluent flow could be checked and monitored (Jager, 2010).

7.3. Actors

The municipality is responsible for the monitoring and proper functioning of the helophyte filters as these are constructed on land owned by the municipality. They were not responsible for the design and construction as this was done by Grontmij nv. After the initial construction was completed the helophyte filters were handed over to the municipality. Several alterations, as mentioned earlier, have since been made. These were done by the municipality (Dijk, 2000; 2010; Jager, 2010).

During construction the Province of Groningen gave the Drielanden a permit to discharge effluent to surface water bodies. This permit was later transferred to the Water Board Noorderzijlvest, who has to make sure that the regulations as stated in the permit are adhered to. However, at the time of research this Water Board was not aware of the helophyte filter being in use, and hence also not of the permit (Ottens, 2010). Because no-one asks any questions about the effluent quality there currently is no monitoring of effluent (Dijk, 2010; Jager, 2010).

The inhabitants are not involved with the helophyte filters at all, except for the knowledge of their existence and that certain chemicals should not be used. There are instances when the inhabitants contacted Mr van Dijk, who is the inhabitant who did his research on the helophyte filters, but this is more often about which chemicals can be used in the household than about a malfunctioning (Dijk, 2010).

7.4. Operation and Maintenance

The operation and maintenance is done by the municipality. However, as different departments (Wijkpost, Wijkbeheer, Stadsbeheer) are responsible for different aspects, inhabitants of the neighbourhood do not know what operation and maintenance procedures are really done (Dijk, 2010; Vinne, 2010). There is a maintenance plan that is written by Mr van Dijk but this is 10 years old and could use an update (Dijk, 2010).

Mr Klopman and Mr de Jager are the persons who are generally in charge of the operation and maintenance of the helophyte filters at the municipality. They generally discuss together when what needs to be done (Jager, 2010; Klopman, 2010). In their decision making they use their own knowledge and judgement as well as Alterra-report 828.1 by Belgers and Arts (2003) as a reference concerning the functioning of the helophytes as well as different maintenance requirements (Jager, 2010).

Maintenance procedures consist of mowing the helophytes and planting new ones, cleaning and maintaining the grates, tanks and pumps and checking, adjusting and cleaning the weirs and valves.

The mowing of helophytes has not always gone well. Jansma (2010) pointed out that in the past this has been done in spring or summer (when the reeds are growing), or it has been forgotten. Furthermore, different techniques have been used to mow the helophytes as this proved to be a difficult task. A flail mower has been used but this resulted in the clippings blocking the grates at the outflow points of the helophyte filters. A mow boat has also been used but due to the density of the helophytes this did not work very well either. In the winter of 2009-2010 the helophytes were mown with a finger bar mower when the water was frozen. This worked quite well as the cuttings could be collected easily and the helophytes were cut at the appropriate length (above the water surface to prevent drowning (Dijk, 2010; Jager, 2010; Vinne, 2010).

Each year, in autumn or winter, 50 per cent of the helophytes are mown, thereby making sure that the other half still functions. This is recorded with a map in which is indicted what half is mown, to make sure that the other half is mown next year. When the helophytes are mown the cascade is flushed and cleaned as well.

The collection tank, in which grease residues collect, is usually emptied each year before the grey wastewater is fed back into the helophyte filter. This is done by a local company for the municipality. The necessity of this action depends on the debris that has accumulated in the trap which is decided upon by the pump operator (Mr Klopman). When the collection tank is emptied the helophyte filters are also inspected and if needed new helophytes are planted in bare spots. The annual inspection also includes a check of the electrical system, the grease trap and the pumps if a malfunction occurred (Dijk, 2010; Jager, 2010; Klopman, 2010; Vinne, 2010).

The grates at the outflow points are controlled every week, and collected debris is removed to prevent flooding (Jager, 2010).

It is estimated by Vinne (2010) that the total operation and maintenance procedures require a total of one week a year. The operation and maintenance costs are discussed in the next section.

7.5. Costs and Financing

7.5.1. Construction

The municipality paid for the construction of the helophyte filters as these formed part of the neighbourhood. Furthermore, Dutch legislation prescribes that the municipality is responsible for the sewage systems in a neighbourhood, which in this case the helophyte filters are considered part of. In addition, the helophyte filters were an essential part of the plans for a sustainable neighbourhood, which the municipality had agreed to help build (see section 7.1). The construction of the two FWS helophyte filters could be financed by the municipality as they had made a profit by buying the land on which the neighbourhood is constructed before the plans were made, and then selling the land on which the houses were built when the actual construction started. As the zoning was changed the land price increased. Unfortunately, the construction costs are not known (Dijk, 2010).

7.5.2. Operation and Maintenance

The operation and maintenance costs are all paid by the municipality. The individual costs could not be retrieved as the activities are taken up as part of the routine municipal maintenance plan for urban green (Jager, 2010).

It is estimated that the costs for cleaning the cascade, mowing the helophytes and collecting and discarding the clippings are not very high. The costs for discarding the clippings are approximately €26.00 per ton, with a couple of tons being estimated to come from the helophyte filters. These clippings are not treated as chemical waste thereby lowering the costs (Jager, 2010).[18]

The emptying of the collection tank is estimated to cost between €200.00 and €250.00 per year (Jager, 2010; Klopman, 2010; Vinne, 2010).

The energy costs for running the pumps and weirs are also not known, but estimated to be very low (Jager, 2010).

7.6. Functioning

7.6.1. Odour Nuisance

As indicated earlier, the initial design had a V-SSF helophyte filter to pre-treat the grey wastewater before it flowed through the FWS helophyte filters. However, due to the dense medium used it rapidly clogged and flooded (Dijk, 2000; 2010), resulting in an odour nuisance. Since the cascade has been constructed and the grey wastewater is mixed with effluent of the first FWS helophyte filter the odour nuisance has lessened to a few times per year. This is not considered a problem as the stench lasts for a relative short time (a day) and inhabitants are used to occasional odour nuisances from the surrounding farmers' fields where manure is applied every year. Some inhabitants of the neighbourhood cannot discern the difference between the stench coming from these fields and the stench originating in the helophyte filters. The stench from the helophyte filters was not found to be worse than that of the farmers' fields and it is accepted as part of life in the neighbourhood (Dijk, 2010).

[18] This is motivated by a study done by the province, which showed that there is no real difference in pollutant concentrations in grass clippings from the first meter of the bank along a road and those removed from 10 metres from the road. As the grass in the first meter of the bank along a road is exposed to runoff containing heavy metals and oils whereas the grass located 10 metres from the road is not exposed to this runoff, it is thought that the uptake of heavy metals and other dangerous pollutants by the grass is minimal. It is assumed that this is also the case with the macrophytes planted in a helophyte filter, and that there are other processes responsible for the removal of the heavy metals and oils (Jager, 2010).

7.6.2. Public Health

The helophyte filters are not considered a threat to the public health. A fence is constructed around the helophyte filter but if one wants to enter it by climbing over, that is possible. However, although the grey wastewater is polluted, it is doubtful if one will get sick when coming in contact with it. For instance, during his research Mr van Dijk has come in contact with the grey wastewater many times and he has never become sick. The risk of drowning in the helophyte filters is present due to the water depth, the accessibility and the fact that it is fully covered with reeds, but this is as likely to happen here as it is in the surrounding canals and ponds and therefore this threat is acceptable (Dijk, 2010).
Dijk (2010) and Jansma (2010) mentioned that during the design and implementation phases certain experts feared that the helophyte filters would result in an increase of the local mosquito populations (and as a result a reintroduction of malaria in the region). This was considered the main threat but over time it has proven not to be true; after 15 years of functioning not a single case of malaria originating in the region has been recorded and the mosquito populations are not larger than normal (Dijk, 2010; Jansma, 2010).

7.6.3. Operational Errors

Apart from the earlier mentioned start-up problems with the V-SSF helophyte filter, the initial unfamiliarity with the technology and clippings blocking the grates during and/or after maintenance took place, no large problems have occurred. The system is equipped with an error notification by phone, meaning that if something is wrong the municipality is notified of this automatically. In the beginning there were some issues with the pumps but this was solved without much problems. Currently the municipality receives an error notification about two times per year which is generally related to the pumps in which debris such as a branch is stuck (Klopman, 2010).
Other than this, the functioning of the helophyte filters is considered very satisfactory and there are no cases of the helophyte filters reacting to chemicals that inhabitants flush down the sinks (Dijk, 2010; Jager, 2010; Klopman, 2010).

7.6.4. Environmental

The condition of the areas surrounding the helophyte filters as well as the surface water quality are used as the main indicators for how well the helophyte filters function (Dijk, 2010; Jager, 2010). Visual assessments are made of the canals, plants and insects in the neighbourhood by the inhabitants and municipality when they visit. These are not recorded. However, Jager (2010) did mention a field study (Kwaadsteniet *et al.*, 2010) that showed that the rare Green Hawker (*Aeshna viridis*) breeds in the Water Soldier (*Stratiotes aloides*) that can be found in the canals in the neighbourhood. The occurrence of these two species, which is related to a good surface water quality (Ketelaar and Wetering, 2000; Lamers *et al*., 2001) is enough reason for the municipality to state that the helophyte filters perform adequately (Jager, 2010).

In the areas where the helophytes are mown Marsh Marigold (*Caltha palustris*) and Purple loosestrife (*Lythrum salicaria*) come up. These do not overgrow the helophytes and add a nice yellow and purple colour to the helophyte filters, and neighbourhood, in spring and summer. These plants are thus not considered to be obnoxious weeds and are not removed (Jager, 2010).

The risk that the helophyte filters will start to leak and that the influent will percolate into groundwater sources is considered absent. There is a thick, well compacted layer of clay under the helophyte filters. Furthermore, the neighbourhood is constructed on clay soils, meaning that if the clay layer is no longer water tight, the clay soils will retain the water. The helophyte sprouts, that can travel several meters through the soil, are not considered a threat either due to these circumstances (Jager, 2010).

7.7. Performance

Unfortunately, the design criteria of the grey wastewater treatment system in Drielanden were not found during this research. Therefore the current situation and functioning cannot be compared to the initial design criteria and assumptions then made. Dijk (2000; 2010) mentions that the helophyte filters were overdesigned as there was a lot of unfamiliarity with the technology. It is unknown by how much this is.

The characteristics of the grey wastewater in Drielanden, measured during various studies in the past (Dijk, 2000; Hernández Leal *et al*., 2007) are provided in the first two columns of Table 7.

The regulations that the effluent that is discharged on surface water bodies has to adhere to, as stated in the permit to discharge effluent to surface water bodies, are provided in Table 10.

Table 10. Permit regulations for effluent that is discharged to surface water bodies in Drielanden, Groningen (Medendorp, 1996)

	Unit	Concentration
BOD_5	mg/l	5.0-10
COD	mg/l	---
N-Total	mg/l	<2.2
TKN	mg/l	---
NO_3^-	mg/l	---
NO_2^-	mg/l	---
NH_4^+	mg/l	---
P-total	mg/l	<0.15
TSS	mg/l	<15
O_2	mg/l	>3
pH	-	6.5-9.0
Temp.	ºC	---

7.7.1. FWS helophyte filters

Dijk (2000) has intensively monitored both V-SSF and FWS helophyte filters during his research. The effluent characteristics of the first and second FWS helophyte filters measured during this time period are presented in Table 11 and Table 12, respectively. Royal Haskoning bv (2008) has analysed the effluent of both FWS helophyte filters in 2008 to check the compliance with the permit to discharge effluent to surface water bodies. The results from this analysis are presented in the last columns of Table 11 and Table 12, respectively.

Of the 17 grab-samples analysed, P-total levels in the effluent of the first FWS helophyte filter exceeded permit regulations 12 times, N-total 4 times, TSS levels two times and pH once. However, in the effluent of the second FWS helophyte filter P-levels exceed permit regulations only four times, of which two were on the same date as those from the first FWS helophyte filter exceeding regulations.

Table 11. Effluent Characteristics of First FWS Helophyte Filter in Drielanden, Groningen

	Units	12-9-1996[1]	9-10-1996[1]	8-11-1996[1]	6-12-1996[1]	16-10-1996[1]	27-11-1997[1]	29-4-1998[1]	11-6-1998[1]	16-7-1998[1]
n	-	1	1	1	1	1	1	1	1	1
BOD_5	mg/l	2.7	3.0	1.4	<0.6	6.1	8.2	3.2	8.2	2.7
COD	mg/l	36	34	33	50	46	55	40	54	53
N-Total	mg/l	2.01	1.31	1.24	2.15	1.63	**3.11**	1.70	**2.50**	**3.31**
TKN	mg/l	2.0	1.3	1.2	2.1	1.6	3.1	1.6	2.4	3.0
NO_3^-	mg/l	<0.01	<0.01	0.04	0.05	0.03	<0.01	<0.10	<0.10	0.31
NH_4^+	mg/l	0.04	0.00	0.02	0.65	0.07	0.05	0.05	0.05	1.30
P-total	mg/l	0.07	0.12	0.11	**0.65**	**0.23**	**0.74**	**0.15**	**0.21**	**0.43**
TSS	mg/l	---	11.5	---	<2.0	7.8	8.5	8.4	3.2	5.2
O_2	mg/l	8.9	9.5	---		---	---	---	---	---
pH	-	7.62	7.63	---	---	---	---	---	---	---
Temp.	ºC	14.0	12.0	---	---	---	---	---	---	---

Table 11. Continued

	Units	20-8-1998[1]	20-9-1998[1]	22-10-1998[1]	22-11-1998[1]	27-5-1999[1]	20-10-1999[1]	23-11-1999[1]	28-5-2008[2, A]
n	-	1	1	1	1	1	1	1	1
BOD_5	mg/l	3.9	2.8	8.9	0.8	2.3	1.7	2.2	4.9
COD	mg/l	46	40	49	23	53	48	34	51
N-Total	mg/l	2.00	2.00	1.80	2.00	2.20	1.00	2.00	**2.50**
TKN	mg/l	1.9	1.9	1.7	1.6	2.1	1.0	1.8	---
NO_3^-	mg/l	<0.10	<0.10	<0.10	0.40	<0.10	---	<0.20	---
NH_4^+	mg/l	0.04	0.50	0.04	0.42	0.11	0.02	0.67	---
P-total	mg/l	**0.17**	**0.59**	**0.50**	0.10	**0.21**	0.12	**0.51**	**0.30**
TSS	mg/l	<2.0	**37.0**	8.2	8.1	<2.0	<5.0	< 5.0	**17.0**
O_2	mg/l	---	---	5.9	---	---	4.6	6.1	7.0
pH	-	---	---	7.26	7.36	---	7.36	7.32	**9.60**
Temp.	ºC	---	---	12.5	---	---	6.5	6.0	16.0

Sources:
1: Dijk, 2000
2: Royal Haskoning bv, 2008

Notes:
A: Sample taken in HF near outflow point

N-total levels exceeded permit regulations two times, with one of the two being on the same date as the first FWS helophyte filter. TSS levels in the effluent of the second FWS helophyte filter were twice higher than permit regulations with one occasion being on the same date as the sample of the first FWS helophyte filter exceeding regulations. The effluent of the second FWS helophyte filter should comply with the permit regulations as the effluent from this filter is discharged into a canal.

The samples taken in 2008 exceed permit regulations in N-total and TSS levels, whereas P-total levels are an all-time low. Royal Haskoning bv (2008) make a side note that at that time the average N-total concentration in surface waters of Groningen was 4.2 mg/l and that earlier measured P-total levels in surface water bodies are also higher than measured in the effluent of the second FWS helophyte filter. Hence they conclude that the higher N-levels will probably not have a negative effect on the surface water bodies of the neighbourhood. From the data it cannot be concluded that there is a steady rise in N-total and/or TSS level (or any other parameter for that matter). The BOD_5 and COD levels measured in this sample are also below permit regulations, and hence the FWS helophyte filters are said to be performing very well.

Table 12. Effluent Characteristics of Second FWS Helophyte Filter in Drielanden, Groningen

	Units	12-9-1996[1]	9-10-1996[1]	8-11-1996[1]	6-12-1996[1]	16-10-1996[1]	27-11-1997[1]	29-4-1998[1]	11-6-1998[1]	16-7-1998[1]
n	-	1	1	1	1	1	1	1	1	1
BOD_5	mg/l	0.7	0.9	1.1	<0.6	0.9	0.8	3.0	1.3	2.5
COD	mg/l	36	29	33	76	30	27	37	37	39
N-Total	mg/l	1.31	1.11	1.23	1.18	1.21	1.31	1.60	1.10	1.70
TKN	mg/l	1.3	1.1	1.2	0.9	1.2	1.3	1.5	1.0	1.6
NO_3^-	mg/l	<0.01	<0.01	0.03	0.28	<0.01	0.01	<0.10	<0.10	<0.10
NH_4^+	mg/l	0.04	<0.02	0.03	0.02	0.04	0.02	0.04	<0.02	0.04
P-total	mg/l	**0.21**	0.06	0.06	0.06	0.05	0.05	0.10	0.09	0.12
TSS	mg/l	---	<2.0	---	<2.0	13.9	8.8	5.2	3.2	<2.0
O_2	mg/l	7.7	8.8	---	---	---	---	---	---	---
pH	-	7.31	7.26	---	---	---	---	---	---	---
Temp.	ºC	12.5	12.0	---	---	---	---	---	---	---

Table 12. Continued

	Units	20-8-1998[1]	20-9-1998[1]	22-10-1998[1]	22-11-1998[1]	27-5-1999[1]	20-10-1999[1]	23-11-1999[1]	28-5-2008[2, A]
n	-	1	1	1	1	1	1	1	1
BOD_5	mg/l	2.1	7.2	2.2	4.8	5.1	1.2	<1.0	<3
COD	mg/l	46	43	26	42	63	46	33	39
N-Total	mg/l	1.80	1.60	1.20	1.30	**3.00**	1.00	1.30	**2.30**
TKN	mg/l	1.7	1.5	1.1	1.2	2.9	1.0	1.1	---
NO_3^-	mg/l	<0.10	<0.10	<0.10	<0.10	<0.10	---	<0.20	---
NH_4^+	mg/l	0.02	0.21	<0.02	0.13	0.22	<0.02	0.02	---
P-total	mg/l	0.14	**0.21**	0.14	**0.30**	**0.21**	0.05	0.11	<0.05
TSS	mg/l	3.7	3.4	**28.0**	6.5	3.9	<5.0	<5.0	**18.0**
O_2	mg/l	---	---	4.6	---	---	5.8	5.5	7.0
pH	-	---	---	6.98	7.03	---	7.32	7.43	7.50
Temp.	ºC	---	---	13.0	---	---	6.5	5.5	16.0

Sources:
1: Dijk, 2000
2: Royal Haskoning bv, 2008

Notes:
A: Sample taken in HF near outflow point

7.7.2. V-SSF helophyte filter

Although the V-SSF helophyte filter was demolished after less than half a year of functioning, Dijk (2000) did monitor its performance during November and December 1996. The influent and effluent characteristics for both months are presented in Table 13 and Table 14, as well as the calculated removal efficiencies. As can be seen, the removal efficiencies of BOD_5, COD, TKN, NH_4^+ and P-total are all above 90 per cent and all concentrations, except pH[19], are within permit regulations.

The concentrations recorded in the effluent of the V-SSF helophyte filter are in the vicinity of those recorded during the same period at the second FWS helophyte filter. The total loads that each helophyte filter had to treat are not known, and neither is the total surface of the V-SSF helophyte filter.

[19] This could be due to anaerobic conditions due to flooding, degradation of organic wastes present in the medium and/or the pH of the loamy soil used as medium.

Table 13. Influent and Effluent Characteristics and Removal Efficiencies of the V-SSF Helophyte Filter in Drielanden, Groningen on 8-11-1996 (Dijk, 2000)

	Units	Influent	Effluent	Removal Efficiency (%)
n	-	1	1	
BOD_5	mg/l	215	3.8	98.2
COD	mg/l	384	38	90.1
N-Total	mg/l	10.91	---	---
TKN	mg/l	10.9	0.8	92.7
NO_3^-	mg/l	---	---	---
NH_4^+	mg/l	3.2	0.02	99.4
P-total	mg/l	1	0.07	93.0
TSS	mg/l	---	---	---
O_2	mg/l	---	---	---
pH	-	6.92	5.92	---
Temp.	ºC	---	---	---

Table 14. Influent and Effluent Characteristics and Removal Efficiencies of the V-SSF Helophyte Filter in Drielanden, Groningen on 8-12-1996 (Dijk, 2000)

	Units	Influent	Effluent	Removal Efficiency (%)
n	-	1	1	
BOD_5	mg/l	122	1.3	98.9
COD	mg/l	221	34	84.6
N-Total	mg/l	5.1	---	---
TKN	mg/l	5.1	0.4	92.2
NO_3^-	mg/l	---	---	---
NH_4^+	mg/l	0.24	0.02	91.7
P-total	mg/l	1.3	0.06	95.4
TSS	mg/l	24	7.8	67.5
O_2	mg/l	0.6	---	---
pH	-	7.22	6.08	---
Temp.	ºC	7.5	---	---

7.8. Perception, Future and Recommendations

7.8.1. Perception

The inhabitants of Drielanden do not find any hindrance from the helophyte filters treating grey wastewater in their neighbourhood. The additional aspect of more urban green and improved surface water quality with all environmental benefits resulting from that result in an overall positive impression of the helophyte filters with both the municipality and, seemingly, the inhabitants.[20] There are some doubts about the investment that will be needed when the helophyte filters, or pumping system, needs to be replaced but as the houses are also connected to the conventional sewage system there is no worry about what will happen with the grey wastewater (Dijk, 2010).

A side note here is that Dijk (2010) expressed that in his opinion the municipality and inhabitants have little interest in the helophyte filters as they hardly seem to be involved with them. This is partly due to the system of the municipality where different departments are responsible for different operational and maintenance procedures. Hence there is no overview of what is happening and what is needed for inhabitants. Mr van Dijk would not feel sorry if it were shut down as a lot was learned from the helophyte filters but it is easier to let the grey wastewater flow into the sewage system (Dijk, 2010).

Surprisingly, the municipality is very positive about the helophyte filter and would not mind having more FWS helophyte filters as the surrounding surface water bodies seem to be clean, they require relative simple operational and maintenance procedures, have low operational costs and produce little waste. The construction costs are not a barrier as the helophyte filters have approximately the same surface area of a pond or green areas in a neighbourhood. The nature value of the helophyte filters is considered very good, and they can be constructed in areas that are classified as a green-zone or on the edge of a neighbourhood thereby lowering the costs related to land prices (Jager, 2010; Klopman, 2010).

[20] Note that apart from the municipality one inhabitant of Drielanden was interviewed. This person (Mr van Dijk) has been conducting research on the helophyte filters (Dijk, 2000) and is the main contact person for inhabitants of Drielanden when they have issues concerning the helophyte filters.

7.8.2. Future

The FWS helophyte filters in Drielanden are expected to continue functioning as they have been doing during the past decade. As they are of the FWS kind they will not clog up, meaning that the medium will not have to be replaced. Sediment and sludge accumulates on the bottom of the reed bed but this is thought to be in small amounts very year and thus far not issues related to this have come up.

It is unknown how long it will last before major aspects will need to be renovated. The overall mind set is that when this happens a solution will be found, but it will not be thought of now.

7.8.3. Recommendations

When constructing a similar system for a neighbourhood, there are several things that are to be kept in mind. The first is that a substantial amount of space is needed, as well as a sewage system to allow for a shutdown in colder times. This means that the overall economic benefit of constructing a helophyte filter, if there is any, is probably very marginal (Dijk, 2010). The operation and maintenance costs are thought to be considerably lower than those of a conventional system. Another point is the stench that can come off the reed beds. This can be substantial on warm days and thus the helophyte filter should be constructed downwind to minimize odour nuisance. Still the inhabitants of the neighbourhood, overall, accept the smell as part of the environment making this a relevant but not decisive argument.

8. Polderdrift

The neighbourhood Polderdrift is located in the south of Arnhem (Figure 12). It is located in the quarter Rijkerswoerd and consists of 40 houses. The grey and black wastewater is collected separately from all buildings. The black wastewater is discharged to the conventional sewage system whereas the grey wastewater is treated by a V-SSF helophyte filter. This is constructed in the middle of the neighbourhood (Figure 13). The effluent is discharged to a tank from where it is used to flush the toilets in the homes.

8.1. History

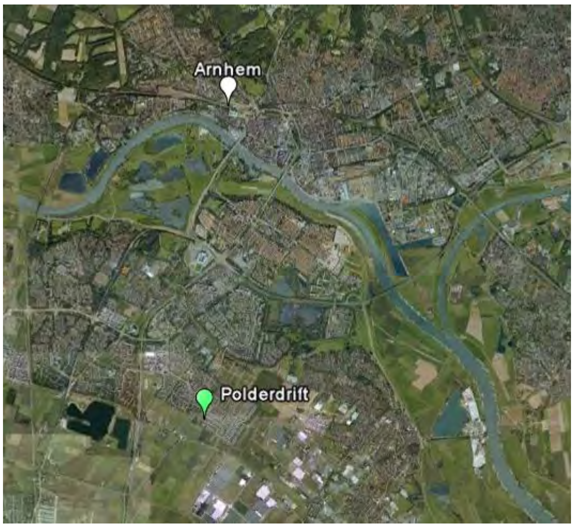


Figure 12. Location of Polderdrift in Arnhem (Google Earth)

In the beginning of the 1990's the municipality of Arnhem was expanding and the quarter Rijkerswoerd was constructed. Part of this neighbourhood, approximately 100 houses, would be ecologically and sustainably sound in all aspects. These houses would become the pride of the new quarter (Beek, 1993). A local alderman (or councillor; wethouder in Dutch) for the municipality of Arnhem, Mr Velthuizen, was the main motor behind these developments and he was a member of a local foundation specially formed to realise the plans for the project. The VIBA, a national Foundation for Integral Biological Architecture (Vereniging Integrale Biologische Architectuur), issued a competition for designing the sustainable and ecological neighbourhood. A winning design was chosen, which would be constructed but then the municipality pulled the plug on the project (Ruijven, 2010a; Velthuizen, 2010; Ven, 2010a). The board of directors of the municipality of Arnhem found that there was a conflict of interest as Mr Velthuizen was an alderman for the municipality as well as a member of the foundation leading the design processes. This was discussed and Mr Velthuizen agreed to terminate his membership of the foundation (Velthuizen, 2010).

The municipality took a new approach and placed advertisements in local newspapers to draw interested people into the project. These people would become the inhabitants of the neighbourhood. The new approach, called collective private ownership, gave the potential inhabitants the opportunity to live in a green suburb and have an influence on the design, construction and living conditions. Over time, however, it became clear that this did not work either. As there was a small group of people who were already interested in, and motivated for, the project the municipality did not want to disappoint them. A new solution was found by alderman Velthuizen, who was still involved with the project as part of the municipality (Ruijven, 2010a; Velthuizen, 2010; Ven, 2010a).

Velthuizen managed to gain the interest of a local housing corporation called the WBVG (Housing Corporation Gelderland; Woningbouwvereniging Gelderland) for the now smaller and less prestigious project. By involving the WBVG not only would the people motivated for the project get their neighbourhood, but it also allowed the relatively small housing corporation to grow and become more viable in the rapidly expanding housing market. However, after the draft plans for the neighbourhood were made it became clear that the WBVG was not able to be responsible financially. The director, Mr Donders, changed employers at that time as well. His new employer, the AWBA (General Housing Corporation Arnhem; Algemene Woningbouwvereniging Arnhem) was a large housing corporation in Arnhem and surroundings and could finance the project. As a result, the project was acquired by the AWBA[21] as well and they approved the final design, financed the construction and have been responsible for the operation and maintenance since completion (Ruijven, 2010a; Velthuizen, 2010; Ven, 2010a).

As the project, now called Polderdrift, was constructed by a housing corporation the inhabitants were not the owners. Instead, they rented the houses. Nevertheless, the people initially involved with the project were also involved by the WBVG and AWBA. The future tenants were able to influence the design and construction processes as they could join different commissions related to design and construction phases. They, for instance, chose the architect in conjunction with the municipality. The tenants were furthermore involved in the decision making processes as they, or representatives, were present at

[21] The AWBA was fused with the Housing corporation Nijmegen (Woningstichting Nijmegen) in 1999 into Portaal housing corporation (Portaal Woonstichting), which in 2002 fused with Foundation Genuagroup (Stichting Genuagroep) to finally form Portaal (Portaal, 2004).

meetings with the WBVG/AWBA and the contractor. Although the tenants had a lot of input, they were not involved in the actual construction but rather played the self-imposed role of watchdog. Overall the AWBA was responsible for the quality and completion of the project. They (now Portaal) are still responsible as it is their property (Ruijven, 2010a; Ven, 2010a).

The inhabitants of Polderdrift are a mixture of all kinds of people. There are elderly people as well as young families living in the neighbourhood. It is not possible to pinpoint one specific character trait that occurs with all inhabitants, except that they are more environmental orientated than average. This, however, is also changing as the initial inhabitants are moving out and new people who were not involved with the realisation of the neighbourhood are moving in. (Ruijven, 2010a).

In the middle of the 1990's the houses of the neighbourhood were completed. The helophyte filter was probably completed in 1997.[22] Although the neighbourhood was still considered ecological, several concessions were made. For instance, sun and wind energy was not used as much as originally planned. On the other hand, the construction materials used were all environmentally friendly and could be reused. The use of PVC-related materials was absolutely minimised. The housed also were constructed with separate piping systems to supply low quality water (rainwater) for laundry purposes and treated grey wastewater for flushing the toilets (Beek, 1993; Ruijven, 2010a).

Five years after the neighbourhood was completed Portaal had to invest a lot of money in repairing or replacing the window frames, which were rotting due to the lack of proper insulation materials that contained PVC.[23] Furthermore, several modifications have also been made to the grey wastewater treatment system. These are described in the next section. Because of these relative large, unforeseen, investments Portaal is now hesitant to invest more money in the neighbourhood. As a result the required rehabilitation of the helophyte filter is not being realised (see sections 0 and 8.8.2 as well) (Ven, 2010a).

Following an incident in Leidsche Rijn (Utrecht, NL) the Dutch government decided that the use of low quality water for household purposes on neighbourhood scale was no longer allowed. In Leidsche Rijn the piping systems were confused and potable water was provided instead of low quality water, and vice versa. This resulted in inhabitants drinking poor quality water (Geel, 2003; Minnema, 2005; VROM, 2009). Because Polderdrift was constructed before 2003 it was able to continue flushing its toilets with the effluent of the helophyte filters. Initially Portaal wanted to shut down the helophyte filter but later changed their minds after the inhabitants protested because they wanted to keep on using treated grey wastewater to flush their toilets. However, research on the threat of the helophyte filter to the public health, with the focus on *Legionella pneumophila*, which causes Legionellosis, was done to ensure public safety. It was found that this threat was not enough to shut down the system. Nevertheless it was recommended to let the piping system fall dry every now and then to prevent *Legionella pneumophila* growth. As a result Polderdrift could keep their grey wastewater treatment system and use the effluent to flush the toilets with, as well as wash the clothes with rainwater (Ruijven, 2010a; Ven, 2010a).

8.2. Technology

The helophyte filter in Polderdrift is a vertical sub-surface flow type. It has an approximate surface area of 230 m^2 and treats the grey wastewater of 40 houses. As on average 2.4 p.e.'s live in one house in the Netherlands, this makes for a total of 96 p.e.'s.[24] The daily grey wastewater production is approximately 10 m^3. The grey wastewater is collected in a grease trap, from where it flows to a pumping tank by gravity. In this pumping tank two pumps are constructed that each supplies one half of the helophyte filter with influent. In case the pumping tank overflows a connection is made to the local sewage system, which also collects the black wastewater. Each pump is programmed to switch on four times per day (24 hours), pumping 2-2.5 m^3 each time. The effluent of the helophyte filter is collected in a separate tank. From here it is pumped to the houses to flush the toilets. An expansion tank is installed to keep a constant pressure on the piping system in the houses. A float valve is installed in the effluent collection tank to allow for filling, with potable water, if the water level drops below a certain point. A meter is

[22] The exact completion date is not known as Velthuizen (2010) mentioned that he changed jobs in 1994 and was sure that the project was completed before he left the municipality. STOWA mentions that the project was completed in 1996 (Swart, 2008), whereas Agudelo *et al.* (2009), Mels *et al.* (2005b), Mels *et al.*, (2009) and Ruijven (2010a), mentioned that construction was finished in 1997. It could be that the different authors refer to different milestones, such as the completion of the houses and finalisation of the helophyte filter. However, this is unclear.

[23] Three years after the neighbourhood was completed a window of one of the houses blew out of its frame during a storm. Inspection led to the find that the laminated pine window frame was rotten at the sill plate. The source of the rot was the moisture in the rabbets as the drainage holes were clogged. These drainage holes clogged easily because the insulation between the glass and the wood was a rubber strip instead of the conventional silicone or glaziers' compound, which resulted in a poorer insulation against moisture. The decision for using the stiff rubber strip instead of the conventional materials was made because of the sustainable and environmentally friendly objectives. In the fifth year after completion Portaal replaced half of all window frames with new ones as they were rotten, and for the other half the glass was removed so that the drainage holes could be enlarged. All windows were refitted with silicone instead of the rubber strips (Ven, 2010a).

[24] The total area per pollutant equivalent is 230/(40x2.4)= 2.4 m^2/p.e..

installed as well to monitor how much potable water flows into the tank. This tank is also connected to the sewage system in case it overflows (Ruijven, 2010a; 2010b).

Figure 13. V-SSF helophyte filter in Polderdrift, Arnhem (Google Earth)

The helophyte filter has a 0.3 m thick clay layer underneath it to prevent the wastewater from infiltrating into the group. This clay was installed and compacted with a crawler excavator by Heijmans nv, who also constructed the houses, sewage system, grease trap, pumping tank, effluent collection tank and piping system. RietLand, a Belgian company constructing helophyte filters, then came in to construct the helophyte filter and lay the influent distribution and effluent collection pipes. RietLand also installed the pumps with their controls. To prevent the 0.2 m thick course sand (10-20 mm) layer, in which the drainage pipes were laid, from being pressed into the clay agricultural plastic was installed on top of the clay. The edges and seams were not made watertight due to the clay layer underneath. On top of the course sand layer lays a 0.8 m thick layer of filtration sand (2-10 mm). No peat or steel slag to bind P was installed as earlier research showed that this could result in clogging. Instead 15 kg of straw was added for every 10 m^3 of filtration sand (Oirschot, 2010; opMAAT, 1996). A second 0.2 m thick course sand (4-8 mm) layer was used to cover the distribution pipes and hold them in place.

One year after completion granulated blast furnace slag was added to the reed bed to bind P. In 2001 the pumps were repositioned as they were falling dry every now and then, resulting in malfunctioning. The reason for this is that these were constructed on the highest point in the grey wastewater system resulting in air collecting in the pumps. At the same time the mechanisms controlling the pumps (float valves) were replaced by timers as the pumps switched on every 15 to 30 minutes and flooded the helophyte filter. These modifications were not done by RietLand but by another company, Henk van Tongeren bv (Oirschot, 2010; Ruijven, 2010a; Ven, 2010a).

The design of the neighbourhood water system was also adjusted during construction. Initially a small water pond would function as a buffer for storing rainwater and to which the effluent tank would overflow, but eventually this just became a surface water body (Ruijven, 2010a).

In 2002 or 2003[25] the effluent coming into the effluent collection tank lessened drastically. This led to studies by different parties. Portaal inspected the pipes by camera, Oirschot (2006) conducted a study and the inhabitants themselves dug holes in the helophyte filter to inspect the drainage pipes and clay layer (Oirschot, 2010; Ruijven, 2010a; Ven, 2010a). Up to now it is not clear what the actual cause is, and approximately 2 m^3 of potable water is added to the effluent collection tank every day to flush the toilets (Ruijven, 2010a).

8.3. Actors

The helophyte filter and grey wastewater system was designed by opMAAT architects. Heijmans nv constructed the houses as well as the sewage system, grease trap, pumping tank, effluent collection tank and the piping systems up to the helophyte filter. They also performed the groundwork for the helophyte filter. RietLand then came in and constructed the helophyte filter and installed the pumps as well as the piping systems within the helophyte filter. A different company, Henk van Tongeren bv, later changed the pump controls (Oirschot, 2010; Ruijven, 2010a; Ven, 2010a).

Although the municipality took the initiative for the neighbourhood and alderman Velthuizen was the main driving factor behind the design processes, it does not own, nor was it responsible for the quality and completion of the project. Hence it is currently also not responsible for Polderdrift. Instead the housing corporation Portaal is the owner of the houses that the inhabitants rent and should therefore control the water used for flushing the toilet (as a house without a functioning toilet is deemed not liveable). They are also the owner of the helophyte filter and hence responsible for it. They pay for the expenses made, but charge the inhabitants a fee for using the helophyte filter (see section 8.5) (Ruijven, 2010a; Ven, 2010a).

[25] Ruijven (2010) stated that this was in 2003, but when asked if the euro was already in use, he replied that this was not the case. Hence the problems with effluent could date to before 1 January 2002.

The inhabitants played a large role in the initial phases of the project. They were part of different commissions and chose the architect in conjunction with the municipality. They were also involved the decision making processes as they, or representatives, were present at meetings with the WBVG/AWBA and the contractor. They were not involved in construction works but did check everything (Ruijven, 2010a).

The inhabitants are the users of the helophyte filter as they produce the grey wastewater and use the effluent for flushing their toilets. The tenants association is responsible for performing simple operational and maintenance procedures as is explained in the next section. They can get reimbursements for the costs they make. Currently two or three inhabitants, including Mr van Ruijven, perform the maintenance procedures and check the functioning of the helophyte filter. Although Portaal is responsible for the other operational and maintenance procedures Mr van Ruijven will perform small procedures himself. He is also the contact of the other inhabitants and Portaal if they have questions about the helophyte filter. Portaal is informed by Mr van Ruijven if the system is malfunctioning (Ruijven, 2010a, Ven, 2010a).

Figure 14. Sponsors of the helophyte filter treating grey wastewater in Polderdrift, Arnhem

Water Board Rivierenland, in whose administrative area Polderdrift is located, is aware of the project but not involved. As the effluent of the helophyte filter is not discharged to surface water bodies no permit is given for this. The harvested rainwater is discharged to surface water bodies but this does not require a permit under Dutch legislation.

The effluent quality has not been analysed except for the time when the system was checked for *Legionella pneumophila* by C-mark, and everything was found to be in good order then (Betuw, 2005) (see Table 31, Appendix 5 for data). The effluent has not been analysed since. As there is no effluent coming from the helophyte filter, and there have been issues with the pumps and blockages, Portaals' view is that monitoring the system will not result in any usable knowledge as it has never functioned properly. The inhabitants are expected to use the helophyte filter and its effluent in a responsible manner (Ven, 2010a).

8.4. Operation and Maintenance

An operation and maintenance manual was provided with the helophyte filter when it was finished. However, this was not written clearly and at the moment of research it could not be found (Ruijven, 2010a). The operation and maintenance procedures are done by means of common sense, practical experience and trial and error.

As mentioned in the previous section, the inhabitants are responsible for mowing of the macrophytes, removing weeds from the helophyte filter and maintaining the surroundings. Minor problems related to the helophyte filter and grey wastewater sewage system, such as blockages, are also solved by the inhabitants.

Portaal maintains the grey wastewater sewage systems, consisting of the piping system transporting the grey wastewater and the grease trap. These are cleaned annually (or bi-annually if deemed necessary), which is the only fixed activity. Portaal will come in when there is a problem with the system or there is a clear need for maintenance. These are usually small, quick projects. However, little maintenance has been done during the past few years (Betuw, 2005). The initial idea was to sign a maintenance contract with an external company but this was never done due to the malfunctioning of the helophyte filter (Ruijven, 2010a; Ven, 2010a).

8.5. Costs and Financing

8.5.1. Construction

The exact construction costs are not known as the helophyte filter was constructed as part of the neighbourhood. However, it is estimated that these were around fl.600,000.- (Mels *et al.*, 2005b; Rousseau *et al.*, 2009). This includes the piping systems for grey wastewater, effluent and rainwater collection and distribution throughout the neighbourhood and in the houses, as well as the helophyte filter. The system was paid for by different sponsors. The sponsors, including the municipality of Arnhem, Water Board Rivierenland, Province of Gelderland, Nuon (energy supplier), AWBA, SEV (Stuurgroep Experimenten Volkshuisvesting; Housing Experiments Steering Group) and Heijmans, are mentioned on a plaque in the building containing the electronics for the pumps (see Figure 14). As this was a unique project in the Netherlands, Polderdrift would be visited by different groups and hence provided an ideal opportunity for increasing the brand awareness (Ruijven, 2010a).

8.5.2. Operation and Maintenance

The operation costs consist of electricity costs for running the pumps and the costs for the additional potable water needed to flush the toilets. The costs for cleaning the piping system are also noted as operational costs (Table 15). These costs are paid by Portaal (Ven, 2010a).

The operational costs differ per year, which could be attributed to the increase in potable water use for toilet flushing as well as an increase in cleaning costs. The latter could have increase as the helophyte filter and grey wastewater piping systems eventually started to clog.

As can be seen in Table 15, the operational costs range between €34.58 (2005) and €109.55 (2008) per house per year. This is excluding renewal costs. The latter, based on the previously mentioned fl.600,000.-, amounts to €340.34 per house per year, based on a lifetime of 20 years and a conversion rate of fl.0.45 for €1.- (excluding inflation rates). However, Ven (2010) mentioned that he proposed to use the fee that the inhabitants pay every month to save for these renewal costs as well, but that the inhabitants were not eager to do this. The reasons for this are unknown.

Table 15. Operational costs of the helophyte filter in Polderdrift, Arnhem (Ven, 2010b)

Year	Activity	Cost (€)
2002	Cleaning, electricity and water bills	2,230.00
2003	Cleaning, electricity and water bills	2,407.20
2004	Cleaning, electricity and water bills	1,382.80
2005	Cleaning, electricity and water bills	1,419.60
2006	Cleaning, electricity and water bills	2,499.60
2007	Cleaning, electricity and water bills	2,757.20
2008	Cleaning, electricity and water bills	4,381.60
2009	Cleaning, electricity and water bills	4,044.80

The main maintenance costs for Portaal come from the inspections done to find out why little effluent is produced (Table 16). The costs for flushing the grey wastewater piping system and cleaning of the grease trap are included in the operational costs. The other maintenance procedures are done ad hoc and the costs are therefore not clear either. Furthermore, as the inhabitants perform part of the routine maintenance procedures such as mowing, the costs associated with this are also not known (Ruijven, 2010a; Ven, 2010a).

Overall, the annual maintenance costs per household ranged between €32.10 (2001) and €105.61 (2006). The total annual costs, per household, in 2006 were €168.10. This was the most expensive year as several maintenance activities were performed.

Table 16. Maintenance costs of the helophyte filter in Polderdrift, Arnhem (Ven, 2010b)

Year	Activity	Cost (€)
2001	Renewing of pumps[26]	1,284.00
2006	Study by RietLand	1,249.50
2006	Camera inspection and maintenance	2,975.00

The inhabitants pay user costs. This was always fl.25.- per household per month. This is currently about €12.- per month. As this is approximately €140.- per year it generally covers the operation and maintenance costs without the renewal costs. The only time that this was not the case was in 2006. The leftover of the monthly fee, after Portaal has paid all maintenance and operation costs, is reimbursed to the inhabitants (Mels *et al*., 2005b; Ruijven, 2010a). Assuming that an annual contribution of €340.34 is needed from each household to save for eventual renewal costs (assuming that one household lives in each house) and that the current user fee is sufficient to cover the operational and maintenance costs, the monthly fee should have been €40.- (€12.- for operational and maintenance costs and €28.- for renewal costs).

As the inhabitants produce less wastewater than average, the Water Board Rivierenland has given them a one-time subsidy of fl.375.- as a stimulation to use the helophyte filter (Mels *et al*., 2005b). The inhabitants still pay the full treatment fee (zuiveringsheffing) to the Water Board. From 1997 till 2001 the inhabitants got a discount of €60.- per household per year on the treatment fee (Betuw, 2005), but from 2002 onwards they have to pay the whole sum. Mels *et al*. (2005b) mention that this is because of Dutch legislation.

[26] Betuw (2005) notes that this was € 10,000.-. In this case, however, the data given by Portaal are adhered to.

8.6. Functioning

8.6.1. Odour Nuisance

Most houses in Polderdrift do not experience odour nuisance. Depending on the wind direction (the predominant direction is south-west (Bleuzé, 1995)), temperature and when the grey wastewater is pumped on the helophyte filter a few houses bordering the helophyte filter in the north can notice the bad odour. This is mainly during the summer. This occurs several times per year (Ruijven, 2010a). Oirschot (2006; 2010) mentioned that the poor pumping regimes could have resulted in the clogging of the helophyte filter, which in turn will result in puddles due to the poor infiltration. These then result in bad odours.

Overall, no formal complaints about the bad odours have been made (Ruijven, 2010a; Ven, 2010a). However, Ruijven (2010a) has been notified about problems with bad odours. When this happens he adjusts the timers of the pumps so that the wastewater is not pumped on the reed bed in the middle of the day, and with a lower frequency.
An explanation for the absence of formal complaints is that the candidate tenants are notified of the helophyte filter before they move into the neighbourhood. This is done during an interview/informational talk about Polderdrift, their objectives and the regulations that are applicable. Hence inhabitants know about the helophyte filter beforehand and perhaps accept the smell (Ven, 2010a).

8.6.2. Public Health

The helophyte filters are not considered more of a threat to the public health than the pond in the neighbourhood or the other surface water bodies surrounding it. In the latter two children can drown, which has never happened, whereas in the helophyte filter it is difficult to even get in contact with the grey wastewater.

The helophyte filter is surrounded by a hedge to prevent children playing in the area from entering it. Nevertheless, children do enter it sometimes. Large flat spots in the helophyte filter also indicate that people have tried to camp there. Up to now, no cases of illness related to the helophyte filter are known (Ruijven, 2010a).

There was a fear for *Legionella pneumophila* accumulating in the effluent tank, but this has been researched and not found relevant (Ruijven, 2010a; Ven, 2010a). The researcher who visited Polderdrift for this research considered it less likely to get a Legionellosis infection from the water used for flushing the toilets than getting the infection from showers after coming home from a holiday (Ruijven, 2010a).

8.6.3. Operational Errors

As mentioned earlier, in 2001 the location of the pumps was adjusted to prevent air from collecting there. At the same time the mechanisms regulating the pumping frequency and duration were adapted. Reason for this was that the initial frequency was too high and not controllable (Ruijven, 2010a). However, Oirschot (2006) mentions that the new installation resulted in a pumping frequency that was too high, which increased the risk of the filtration sand in the helophyte filter clogging up. This potential clogging was also seen in the top layer of the helophyte filter where a lot of solids had accumulated. Because of the accumulated solids in the top layer the influent was not distributed properly throughout the helophyte filter. This resulted in puddles and hence a production of bad odours. The water in these puddles would flow back into the influent-distribution piping system and then back into the pumping tank. Here it would overflow into the conventional sewage system. This would explain why there is no effluent (Oirschot, 2006; 2010). During his visit Oirschot (2006) also found that the grease trap was not constructed properly, which resulted in several blockages. This was fixed during his visit.

On the contrary, Ruijven (2010a) believes that there is no effluent because the clay layer at the bottom of the helophyte filter is leaking. His motivation is that the influent cannot flow back into the pumping tank because he removed the influent-distribution piping system from the course sand layer and left it lying in the open air on top. He also measured the back flow of effluent and calculated this to be a fraction of the wastewater that was pumped on the helophyte filter per turn (0.3 m^3 of the 2.5 m^3) (Ruijven, 2010b).

Oirschot (2006; 2010), Ruijven (2010a) and Ven (2010a) all mention that if proper functioning of the helophyte filter is desired, it will need a complete renovation. However, according to Ruijven (2010a) the financial means for accomplishing this were not present, whereas Ven (2010a) stated that when given the opportunity to save money for rehabilitation the inhabitants were reluctant. Portaal is the owner of the neighbourhood and they have had to invest a lot in it since completion. Ven (2010a) explained that even with all these investments the neighbourhood was still not in the state that it should be. This has resulted in Portaal being hesitant to invest more, and hence its desire that the inhabitants invest in the new helophyte filter.

Since this research started some action has been taken as Oirschot (2010) mentioned that someone has asked him to give an estimate on how much it would cost to rehabilitate the helophyte filter. This was confirmed by Ruijven (2010b). Ruijven (2011) also mentioned that the tenants association asked Portaal to find out how much the rehabilitation of the helophyte filter would cost. During this meeting Portaal said that they would do this (see the last part of section 8.8).

8.6.4. Environmental

The little effluent of the helophyte filter that is produced is not discharged to surface water bodies but to a storage tank, meaning that its influence on the surrounding water bodies is minimal. On the other hand, if the clay layer is leaking as Ruijven (2010a) suspects, the grey wastewater, after it flows through the bed, could be infiltrating into the groundwater. This has not been proven, and as the grey wastewater is treated by the helophyte filter before it reaches the clay layer it is thought that it will not have a negative impact.

Ruijven (2010a) mentioned that the vegetation around the helophyte filter is lusher during hot and dry summers than vegetation in other areas of the neighbourhood. This vegetation, consisting of trees and the hedgerow around the helophyte filter, also results in the accumulation of organic matter, such as leaves, in the helophyte filter.

Weeds, such as hedge bindweed (*Calystegia sepium*) are also found in the helophyte filter. These are periodically removed by the inhabitants but return continuously. This results in bare spots where no macrophytes grow.

8.7. Performance

Bleuzé (1995), as employee of opMAAT, wrote the design concept for the helophyte filter in Polderdrift. Based on similar but unnamed cases from Germany he predicted a 40 per cent reduction in water consumption and an 85 per cent reduction in wastewater production in Polderdrift. Pötz and Bleuzé (1998) mention that this was 57 per cent and 85 per cent, respectively.

The design of the helophyte filter is based on a grey wastewater production of 83 l/c/d (Bleuzé, 1995) and a surface area of 2 m^2/p.e. (Oirschot, 2010). Table 17 shows the assumed characteristics as the grey wastewater leaves the house (At source), as it leaves the grease trap (influent) and as it leaves the helophyte filter (effluent). The assumed treatment efficiency is also shown.

Table 17. Assumed influent and effluent characteristics of helophyte filter in Polderdrift, Arnhem (Bleuzé, 1995)

	At source	Influent	Effluent	Removal efficiency
	mg/l	mg/l	mg/l	(%)
BOD_5	253	190	10	94.7
COD	409	383	26	93.2
N-total	12	5	0.3	94.0
P-total	5	3	2	33.3

Based on the coarseness of the sand, the infiltration capacity of the helophyte filter was assumed to be 30-40 m per day. During use this will lessen by a factor 10 as solids accumulate and biological growth occurs. However, the infiltration capacity of 3-4 m/d would still be enough as only 0.05 m of grey wastewater needs to infiltrate (Oirschot, 2010) (based on 10m^3 of grey wastewater spread over 230m^2). Hence in theory no puddles should occur.

Soons (2003) in Betuw (2005) has analysed four grab samples from the grease trap. These are provided in Table 18. As mentioned earlier, effluent has only been analysed by C-mark during their research on the threat of Legionellosis. These results, as found in Betuw (2005) are presented in Table 31, Appendix 5. Due to the different parameters analysed and the different time periods during which the samples were taken a comparison could not be made.

When Table 18 is compared with Table 17, it can be seen that the BOD concentrations assumed are lower than those measured. On the contrary, COD concentrations are lower. N concentrations are also higher in the measured influent, whereas the measured P-total concentrations are similar to those assumed.

Table 18. Influent characteristics of helophyte filter in Polderdrift, Arnhem (Soons (2003) in Betuw, 2005)

	Units	*n*	Mean	Spread
BOD_{20}	mg/l	1	283	---
COD	mg/l	4	322	296 – 342
TKN	mg-N/l	4	19.6	11.1 – 28.3
NH_4^+	mg/l	4	4.8	1.4 – 5.9
P-total	mg/l	4	3.3	2.5 – 5.6
E.coli	cfu/100ml	4	$7.7x10^5$	$1x10^5$–$220x10^5$

When comparing the measured influent values to the Dutch grey wastewater characteristics (Table 7), the BOD concentrations are within the general range, but on the low side. COD concentrations are lower than those found in literature, whereas TKN values are higher. NH_4^+ concentrations are similar, as opposed to P-total concentrations being lower. Lastly, *E.coli* concentrations, compared to European grey wastewater characteristics, are on the high end.

Concluding, the assumed influent characteristics are not always similar to the field conditions. Although P-total concentrations were similar, BOD and N-total concentrations were lower. The assumed COD concentrations were higher than those measured, but both are lower than those found in literature. The influence of the wrongly assumed influent characteristics is, unfortunately, not known, as the effluent has never been analysed for similar parameters.

8.8. Perception, Future and Recommendations

8.8.1. Perception

It is said that the helophyte filter is perceived as a positive addition to the neighbourhood by the inhabitants. The living conditions in the neighbourhood are improved as the amount of green increases. The space between houses is larger than average as well (due to the piping systems and landscape architecture), resulting in a 'phenomenal environmental quality' (Ruijven, 2010a). It should be noted that the helophyte filter is not labelled as a 'green image' booster, but more as an intriguing project in the neighbourhood. Although not all inhabitants are very active in maintaining the helophyte filter, they are aware of its existence and purpose and restrictions on using certain chemicals. This is not found to be an issue. There is no way to check if this is adhered to. As new inhabitants are told of the helophyte filter, its purpose and what chemicals cannot be flushed through the sink no problems related to this matter have occurred (Ruijven, 2010a).

The only negative aspects are the noxious odours that are produced on warm days and the blockages that have occurred in the sewage system. Although no complaints have been made both issues have occurred several times per year, which can become tiresome (Ruijven, 2010a). Nevertheless, the inhabitants would rather have a rehabilitated helophyte filter than no helophyte filter at all (Ruijven, 2011).

It should be noted that the inhabitants have the idea that Portaal is not very interested in the helophyte filter, and that Portaal has tried to shut it down several times. Although this has never happened as the tenants association did not agree with it, Portaal is not very active and only acts when there is an acute problem (Ruijven, 2010a).

On the other hand, Portaal is positive about the neighbourhood and its initial objectives. However, despite the investments in the neighbourhood made since its completion, the helophyte filter, with the grey wastewater sewage system and effluent distribution pipes, has never functioned as well as it should have. As Polderdrift is not perceived as a special case by Portal (which could be a reason for investing more in a certain project), it is now hesitant to invest more in the neighbourhood (Ven, 2010a).

8.8.2. Future

As the helophyte filter is not functioning properly, and Portaal doubts that it ever will, there are few incentives to invest in the current system. However, other water systems in the neighbourhood such as the rainwater system that provides water for the laundry machines, do seem to be functioning well. There is a good chance that Portaal will let the system be as it is, and continue plodding on as there is no health threat at the moment (Ven, 2010a). As mentioned earlier, Portaal has proposed to use the remaining money of the fee that the inhabitants pay for the use of the helophyte filter to save for a complete rehabilitation. Then the inhabitants were not willing to do this, but when later contacted, Ruijven (2011) stated that the tenant's organisation had contacted Portaal about investigation how much the renovation would cost. Portaal was willing to do this.

There is a possibility that the future inhabitants will not be willing to invest time in the maintenance of the helophyte filter. This is currently already minimal and there is a very low, if no, return for the inhabitants due to the poor functioning. The inhabitants do not really notice that their grey wastewater is being treated and there are no real financial motivations to use the helophyte filter either. Furthermore, the conventional sewage system can easily be used to transport the grey wastewater away to the wastewater treatment plant at no higher costs for the inhabitants. As (future) users were not part of the initial planning and construction of the neighbourhood, they are less 'bound' to the helophyte filter and would be more willing to discard it (Ruijven, 2010a).

Concluding, it seems that the helophyte filter will be left as it is; producing very little effluent and a bad odour when air temperatures are high. Although there is some movement towards rehabilitating or discarding the whole grey wastewater treatment system it is still uncertain if any action will be undertaken. In case the helophyte filter is rehabilitated, it would provide an excellent opportunity to not only learn about the costs related to this, but also how this can be done, as it has never been done (at least, recorded), before in the Netherlands and abroad. Another potential study is the existence of P in the bed. This could provide more insight into where, and to what, the P binds, accumulates and how the binding and adsorption of P could be enhanced in future designs.

8.8.3. Recommendations

The future use of a helophyte filter for grey wastewater is recommended by Ruijven (2010a) and Ven (2010a) as it is thought to treat grey wastewater adequately and adds environmental value to the neighbourhood. There are, however, a few critical side notes of which the first is the need for a helophyte filter. As the construction of a helophyte filter is expensive and the houses could also be connected to the conventional sewage system there should be enough motivation for constructing, operating and maintaining the helophyte filter. All three aspects are vital to ensure proper functioning as Polderdrift has shown. A poorly constructed helophyte filter will not function properly, resulting in less motivation to maintain it properly. In some cases it is more sustainable to use less environmentally friendly construction materials that have a long life span than using very environmentally friendly materials that have a short lifespan or do not perform well.

When designing the pumps and piping systems aspects such as accessibility for maintenance purposes, and measures to prevent flooding, air entrapment and blockage should be included. Furthermore, the proper construction of the tanks and grease trap is also essential for guaranteeing a good functioning grey wastewater treatment system (Ruijven, 2010a).

The users of the helophyte filter need to be continually reminded of the way the piping systems are installed in their homes to make sure that they do connect the different water systems during construction works or modifications to their homes (Rousseau *et al.*, 2009). They should also be motivated to properly use the helophyte filter by not using certain chemicals.

Motivation is perhaps the most important aspect of a properly functioning helophyte filter. Not only during the initial design and construction phases, but also when repairing, operating and maintaining it. Sometimes a lot of effort and (financial) input is needed and when this is not done properly, the returns of that input can be minimal. The costs of constructing and maintaining a helophyte filter are not low, and therefore should be properly estimated beforehand.

9. Lanxmeer

The neighbourhood Lanxmeer is located in the south-west of Culemborg (Figure 15). There are approximately 250 houses and apartments constructed in the neighbourhood and construction is still going on. There are also several companies and offices, as well as a large secondary school[27] (Junior High, VMBO, HAVO, and VWO). All buildings, except the *VWO* location, which was constructed in 1994, collect the grey and black wastewater separately after which the grey wastewater is treated by three individual V-SSF helophyte filters. These are located throughout the neighbourhood (Figure 16) and discharge their effluent in local surface water bodies (canals). It should be noted that Vitens nv pumps up ground water from under the neighbourhood for drinking water production. Hence there are no buildings in the middle of the neighbourhood but an orchard (BEL, 2003; Hooijer, 2011a; Koning and Hooijer, 2011; Swinkels and Boland, 2010).

9.1. History

In 1994 the EVA-foundation (Ecologisch Centrum voor Educatie, Voorlichting en Advies; Ecological Centre for Education, Information and Advice) was formed. Its main mission was to bridge the gap between the environmental policies of the government and society by increasing awareness, advocacy and involvement. This would be done by involving different facets (architecture, landscape architecture, energy, agriculture, higher education, health care and art) and closing the resource cycles, thereby producing minimal waste. These were formed into the eight ambitions shown in the textbox on the below (BügelHajema, 2010; Stichting EVA, 2005; Swinkels and Boland, 2010; VROM, 2009).

Figure 15. Location of Lanxmeer in Culemborg (Google Earth)

The EVA-foundation wanted to make these ambitions practical by constructing a neighbourhood in which they played a key role and inhabitants would be involved in the design and management processes of the neighbourhood. They would also participate in different activities such as energy production, maintenance, and agriculture. The aim was to make this a nation-wide example of how people could live in an integrated, ecological and sustainable city. Ms Marleen Kaptein, the founder of the EVA-foundation, took the initiative and approached the municipality of Culemborg with these ideas. The municipality liked the innovative concepts and in 1996 a joint project team was formed. BügelHajema and Copijn made the zoning plans, overall neighbourhood designs and landscape plans after which the architect Joachim Elbe designed the urban layout. Specific aspects and buildings in the neighbourhood were designed by different engineering bureaus but these adhered to the overall design by Elbe (BEL, 2003; Hooijer, 2010a; Stichting EVA, 2005; Swinkels and Boland, 2010; VROM, 2009).

1. Architecture in relation to landscape; using the Genus Loci
2. Integration of functions: Living, working, education and recreation
3. Sustainable water provision and integrated water management
4. Sustainable energy provision
5. Mobility: lessen car use and minimise the presence of cars in neighbourhood
6. Use of ecological construction materials
7. Participation of future inhabitants
8. Education and advice

The municipality functioned as the project developer for the first half of the neighbourhood (north-western part). They financed the construction of the houses and sold them as well. A part of the neighbourhood was sold and rented to tenants by the local housing corporation (Kleurrijk Wonen). The second part of the neighbourhood was financed by an external project developer. However, as the houses did not sell as quickly as expected, the search for a third project developer for the south-eastern part of the neighbourhood is taking longer than expected. This area was initially zoned for offices as it was considered less suitable for houses due to higher levels of noise

[27] This school, the ORS Lek en Linge, consists of four different buildings in which four different secondary school-phases are located. The first location, located along Multatulaan 6, was constructed in 1994 and houses the VWO secondary school. The second location was constructed in 2005 and houses the Junior High (brugklas). This is located along the Annie M.G. Schmidtpad 1. The third location, on the Ina Boudier Bakkerstraat 2, was finished in 2008 and is for the VMBO secondary school. Lastly, along the Multatulilaan 3 the building for the HAVO secondary school was finished in 2011. Of these four buildings the *VWO* location is not connected to a helophyte filter. The *Junior High* and *HAVO* locations are connected to the *School* helophyte filter, whereas the *VMBO* secondary school is connected to the *Unie* helophyte filter (Koning and Hooijer, 2011).

coming from the railroad and road (N320). However, due to the lower demand for office space (probably a result of the financial crisis of 2007) the plans have changed and apartments and houses will be constructed here (Hooijer, 2010a; Swinkels and Boland, 2010).

The buildings constructed in Lanxmeer are considered sustainable, energy efficient and ecologically sound. In the beginning a lot of decisions were made during group meetings. All plans were discussed and amended if necessary as they had to adhere to the wishes of the EVA foundation, as well as the urban design and legal legislation. All parties agreed upon the final plan that had little concessions from the original aims of the EVA-foundation. Construction of the neighbourhood started on 5 February 1999 and the first houses were completed in March 2000 (BEL, 2003; Hooijer, 2010a; Stichting EVA, 2005). During construction Dutch legislation regarding the use of treated wastewater for toilet-flushing changed, as explained in section 8.1 (Geel, 2003; Minnema, 2005; VROM, 2009). As a result many of the houses have a double piping system installed to provide two different quality-types of water, but potable water comes from both.

People living in Lanxmeer range from young families with children (there are relatively a lot of children in the neighbourhood) to retired people living together in a group of houses. The majority of these people were interested in, and looking for, an environment that was ecological and sustainable; as the main aspiration was to construct a sustainable, environmentally friendly neighbourhood (which is more expensive to construct due to the building materials and strict norms regarding energy emissions) people who valued this were drawn into the project. Besides this, inhabitants also have some rules and regulations (e.g. concerning the use of the helophyte filters, washing cars, parking cars) to live by that are not usual for the average Dutch neighbourhood. Thus the people that live in Lanxmeer are considered more ecological and sustainably oriented than the average Dutch person. This does result in less potential buyers for the houses in the south due to the reasons mentioned previously (Hooijer, 2010a).

The initial inhabitants were people who embraced the ideas of the EVA-foundation and who were active with the design phase. However, people who moved into the neighbourhood after these phases were completed were not as involved and hence do not feel the same towards the ideas of the EVA-foundation. This results in some minor frictions. Although there is a 'division' between these two groups of people this is not very big and relevant in the daily lives (Rijk, 2008; Swinkels and Boland, 2010). All of the inhabitants are member of the neighbourhood association BEL (Bewonersvereniging EVA-Lanxmeer; Inhabitants Association EVA-Lanxmeer) and the majority also actively participate with their activities.

Black and grey wastewater are collected and transported separately in the neighbourhood. Rainwater from roofs and surface runoff are also collected and transported separately. Initially, the black wastewater would be treated with a biogas installation to produce energy. The grey wastewater is treated with the helophyte filters and rainwater and surface runoff is discharged of in local surface water bodies. The concept of treating black wastewater locally was discarded of due to the low amounts of gas produced and the unwillingness of the energy provider (Nuon) to buy this gas; the black wastewater now goes to the local wastewater treatment plant (Hooijer, 2010a; Meijer *et al.*, 2010; Mooi, 2003).

Arcadis was responsible for the design of the helophyte filters. Arcadis in turn employed BrinkVos Water to design and construct the helophyte filters. A local construction company, Gebr. van Santen, performed the construction works. These started in 2000 after the first houses were completed. The helophyte filters were fully operational in 2003. The houses that were finished before the helophyte filters were constructed were connected to the helophyte filters afterwards (Hooijer, 2010a).

There were not a lot of issues to deal with concerning the helophyte filters. There were no drawbacks and construction was relatively simple. It was very important that everybody worked accurately for the helophyte filters to function correctly (Hooijer, 2010a).

9.2. Technology

The grey wastewater produced by more than 250 houses and 5 office buildings in Lanxmeer is treated with three helophyte filters, all of the V-SSF type (Figure 16). As construction is still going on, the number of houses and office buildings is an estimate. Nevertheless, with the Dutch average of 2.4 p.e.'s per house the total number of p.e.'s is more than 600. This is excluding the employees of the different companies located in Lanxmeer. As the total number of offices and companies, with the number of employees, is not known, the p.e.'s for these offices and companies could not be calculated.[28]

The helophyte filters in Lanxmeer are located opposite the train station in the north-west (*Station*), next to the school Lek en Linge in the east (*School*) and along the road to the Unie in the south (*Unie*). Each helophyte filter treats the grey wastewater from a different part of the neighbourhood. Whereas the

[28] A full time employee working in an office is noted as 1/3 p.e. in the Netherlands (VROM and KIWA, 1998).

Station helophyte filter is fully in use, the latter two are functioning at about 50 per cent of their capacity as not all planned buildings are completed yet. As the part of the plans for the southern part of Lanxmeer have changed from offices to houses it is not yet known how much more houses, or offices, will be connected to the grey wastewater system.

Figure 16. V-SSF helophyte filters constructed in Lanxmeer, Culemborg (Google Earth; Verhaagen, 2007)

Within the neighbourhood the grey wastewater sewage system is laid in such a way that the grey wastewater of 50 houses comes together into one pipe, which then flows towards the grease traps (Mooi, 2003). Each helophyte filter has one large grease trap located near the tank in which two pumps are installed. The grey wastewater flows by means of an overflow from the grease trap into the pumping tank that has an estimated capacity of 6 to 10 m^3. In each pumping tank two electric pumps are installed on the bottom, which are activated by a float switch. The pumps switch off automatically when the grey wastewater depth is an approximate 0.25m. The volume of grey wastewater that is pumped onto the helophyte filter at once is calculated to be half of the daily produced grey wastewater that the helophyte filter has to treat. In general this happens between two and five times per 24 hours depending on local grey wastewater production (Hooijer, 2010a; 2010b; 2011; Vos, 2011).

The total surface area of the three helophyte filters[29] is 4300 m^2. This is divided over the three helophyte filters as follows (Hooijer, 2010b; Municipality of Culemborg, 2003):
- The *Station* helophyte filter consists of three different reed beds, each with a total surface area of approximately 300 m^2. There is one tank from which the influent is pumped to the three beds. The effluent of the three reed beds also goes to one collection point, which is a small tank. From here it is pumped to a surface water body on the other side of the street (Parallelweg Oost) by means of a culvert.
- The *School* helophyte filter consists of one reed bed with an approximate surface area of 1500 m^2. The influent comes from one tank and the effluent is discharged into a nearby canal. This is done via a pipe that lies under the parking lot at the end of the Annie MG Schmidt path.
- The *Unie* helophyte filter also consists of one reed bed with an approximate surface of 1500 m^2. The influent also comes from one pumping tank, from where it is pumped on the reed bed. The effluent flows via a short pipe into an adjacent canal.

Each helophyte filter has a 1.0 m deep bed with PVC foil on the bottom to make it watertight. On this foil lays a 0.2 m layer of gravel (8/16 mm) in which the drainage (80 mm) pipes are laid, 0.7 m of filtration sand (100-500 μm) and lava stones (8-16 mm) and a 0.1 layer of gravel (8-16 mm) on top in which the influent pipes (40 mm) are installed. These pipes are not glued together but fitted by hand for inspection, repair and maintenance purposes. They are held in place by the gravel (Bloemerts, 2011, Hooijer, 2010a). In case of a blockage or power failure each tank has an overflow to the black wastewater sewage system that leads to the local wastewater purification plant.

The helophyte filters are in use year-round and seem to be functioning properly. The Water Board Rivierenland performs annual checks in the form of grab samples to make sure that the effluent complies with the permit to discharge to surface water bodies (see section 9.7). These checks are done at a random date and time to ensure that the helophyte filters meet the required standards throughout the whole year. As Lanxmeer is constructed in an area where drinking water is extracted from the ground, Vitens nv has also, once, analysed the effluent as part of an EET study in 2007 (SenterNovem, 2008).

Since the helophyte filters have been constructed no alterations have been made. They function well, with the note that more maintenance (weeding) is required than expected (see section 9.4).

9.3. Actors

The municipality is responsible for the monitoring and proper functioning of the helophyte filters. This is because the helophyte filters are constructed on land owned by the municipality and are part of the local sewage system. BrinkVos Water was asked by Arcadis, who was designing the urban green areas, to design the helophyte filters. Gebr. van Santen, a local construction company, then constructed the

[29] Current total area per pollutant equivalent is 4300/(250x2.4)= 7.2m^2/p.p.. Note that companies and offices are not included as the number of employees is not known, and that construction is still going on, which means that the actual surface area per p.e. is smaller.

helophyte filters, as explained in the previous section (Hooijer, 2010a; Meijer *et al.*, 2010; Santen, 2010; Swinkels and Boland, 2010).

When the helophyte filters were finished the Water Board Rivierenland gave a permit to discharge effluent to surface water bodies for the three helophyte filters. The municipality has to make sure that these regulations are met, which the Water Board checks.

The inhabitations of Lanxmeer, with the secondary school and several offices and companies are the producers of the grey wastewater. The inhabitants association BEL monitors and manages activities, maintenance and construction plans and the general environment in the neighbourhood. There are several comities formed by this organisation with specific tasks. One of these, Terra Bella, is responsible for the maintenance of all urban green in the neighbourhood except for the helophyte filters as these are considered part of the sewage system. Nevertheless, this committee does keep an eye out on its state and functioning and they will notify BEL or the municipality if anything seems to be wrong (Hooijer, 2010a; Swinkels and Boland, 2010).

9.4. Operation and Maintenance

The helophyte filters are operated and maintained by the municipality. The inhabitants are aware of what is happening and are sometimes updated as well (Hooijer, 2010a). Copijn (2003) wrote a maintenance plan for the neighbourhood with a separate chapter about the helophyte filters. The main maintenance aspects mentioned here are mowing the reeds and what to do if the helophytes are invested with insects (Aphids (*Aphidoidei* sp.) and Twin-spotted Wainscot (*Archanara Geminipuncta*)). If the latter occurs it is advised to burn all macrophytes. However, it is noted that the infestation with these insects can be minimised by annual mowing.

Mr Hooijer is generally in charge of the operational and maintenance aspects, although the latter are performed by the maintenance department of the municipality. He, as well as the inhabitants, monitors the state of the helophyte filters and if something is wrong Mr Hooijer takes action to solve this.

The helophyte filters are easy to operate as everything functions automatically. The grey wastewater and effluent either flows by gravity or is pumped away. These pumps are controlled by float switches and run on electricity. The grey wastewater treatment system is controlled five times per year and as long as it functions properly, it is left as it is.

The reeds are mown mechanically every year in autumn when the leaves start to turn brown. The clippings are discarded off via a waste management company. The top gravel layer of the reed bed is also inspected annually and replaced where needed. This is necessary as sand accumulates in the gravel and certain weeds can grow extensively here. In the spring of 2010 some foreign species (Hedge Bindweed, *Calystegia sepium*, and grass) invaded the *Station* helophyte filter in such a way that whole patches of macrophytes were gone. A lot of weeding (4-5 weeks with 4-5 people) was needed to remove these by hand but by the autumn of 2010 they were springing up again. It is estimated that annually 70 per cent of the top gravel layer needs weeding and/or replacement of gravel.

Mr Hooijer checks the pumping tanks and makes sure that the pumps are serviced annually. The piping system is only checked for loose connections that leak. These are found when large wet spots are visible in the helophyte filter. This is solved by simply joining the two pipes again. The piping system is not flushed every year. There is some microbial growth and accumulation of solids in the pipes but this is not more extreme than in conventional sewage pipes and hence flushing is not considered necessary. It does occur that the end-caps come off and this is generally noticed as a large puddle will form in the reed bed. The end cap will then be pressed on the pipe again.

9.5. Costs and Financing

The costs given below were provided by the Management and Operation department of the municipality of Culemborg and are an overview of 2010 (Hooijer, 2010b).

9.5.1. Construction

Construction costs were paid by the municipality as the helophyte filters are considered part of the sewage system in the neighbourhood. These were more expensive than the construction of a conventional sewage system for a similar neighbourhood as more sewage pipes were installed (four individual sewage systems in the neighbourhood and the piping systems in the helophyte filters). The movement of soil and import of gravel and sand for the helophyte filter beds also required a large investment (Hooijer, 2010a).

Table 19. Construction costs of helophyte filters in Lanxmeer, Culemborg (Hooijer, 2010b)

Activity	Cost (€)
Helophyte filters	350,000.00
Pumps	70,000.00
Pumping tanks	30,000.00

The total construction costs for the three helophyte filters were €450,000.-, of which €100,000.- was used for the pumping tanks. Of this, €70,000.- was used for the pumps and related parts and €30,000.- for the tanks (Hooijer, 2010b) (Table 19).

With 250 houses constructed in the neighbourhood the total construction costs were €1800.00 per house. As more buildings are constructed in Lanxmeer, the costs per house will become lower.

9.5.2. Operation and Maintenance

The operation and maintenance costs were paid for by the municipality. However, as each household in Lanxmeer pays an annual fee per building for the use of the sewage system (rioolrecht) the municipality is refunded for its costs. The maintenance requirements proved to be more expensive than thought as the high demand for weeding and gravel replacement was not anticipated (Hooijer, 2010a).

The operational costs (Table 20) of the helophyte filters consist primarily of controlling the system and running the pumps. The costs for controlling and maintaining the water level, which is done five times per year were €120.- (3 measurement points, 5 times per year at € 8.- per point per control). The costs for running the pumps were €1,500.00 for electricity (€500.- per pump) and €1,500.- for the phone bills (€500.- per pump) (Duren, 2011; Hooijer, 2010a; 2010b).

Part of the operational costs is the renewal of material. The pumps are assumed to be renewed every 15 years resulting in a total annual cost of €4,666.67 (€1,555.56/location). The lifespan of the helophyte filters is assumed to be 25 years, resulting in an annual renewal cost of €14,000.- (€4,666.67/location). The lifespan of the tanks containing the pumps are assumed to be 30 years, resulting in an annual cost of €1,000.- (€333.33/location). Note that inflation is not included in these calculations.

Table 20. Operational and renewal costs of helophyte filters in Lanxmeer during 2010, Culemborg (Hooijer, 2010b)

Activity	Cost (€)
Controlling and maintaining water level	120.00
Electricity	1,500.00
Phone bill	1,500.00
Renewal of helophyte filter	14,000.00
Renewal of pumps	4,666.67
Renewal of pumping tanks	1,000.00
Total:	**21,786.67**

The main maintenance costs (Table 21) consisted of mowing the helophytes, discarding the clippings and maintaining the gravel beds and pumps. The total costs for mowing the helophytes were €1,934.- (€0.45/m^2) and discarding the clippings were €3,655.- (€0.85/m^2). The weeding and replacement of gravel where needed (about 70 per cent of the total surface area) cost €6,923.- per year (€2.30/m^2). The maintenance of the pumps cost €4500.- per year (€1500.-/pump).

Table 21. Maintenance costs of helophyte filters in Lanxmeer during 2010, Culemborg (Hooijer, 2010b)

Activity	Cost (€)
Mowing helophytes	1,934.00
Discarding clippings	3,655.00
Weeding and replacing gravel	6,923.00
Maintenance of pumps	4,500.00
Total:	**17,012.00**

The total annual operational costs, excluding the renewal costs, were €3120.-. Assuming 250 households in the neighbourhood this is €12.48 per household. The annual total costs for renewing the helophyte filters and pumps were €19,666.67. This is €78.67 per household. The total annual maintenance costs were €17,012.-, which is €69.05 per household.

The total annual operation and maintenance costs, per household were €80.53, without renewing the helophyte filters and pumps. If the latter two are included, the total annual operation, maintenance and renewal costs are €159.19 per household. This is paid for by the municipality.

Duren (2011) estimated that the sewage system has a length of 2 kilometres in the neighbourhood. As there are four sewage systems in the neighbourhood the total length is a maximum of 8 kilometres.[30] This is flushed every 7 or 8 years at a cost of €2.- to €3.- per metre. This is an average annual cost, per household, of €8.- to €13.71. It should be noted that these are only maintenance costs. There are also construction costs, renewal costs and policy-making costs. It is estimated that these maintenance costs should be multiplied by a factor 9 to get an indication of the total operation and maintenance costs for the neighbourhood (Stichting RIONED, 2010; Oosterom, 2011). This results in an indication value of €72.- to €123.39.

The latter calculation shows that the total annual costs of the sewage systems and helophyte filters in Lanxmeer were between €230.- and €285.- in 2010.

As explained earlier, each household in the Netherlands pays an annual fee to the municipality for the use of the sewage system (Sewage rights; Rioolrecht). In 2010 this amounted to an average of €239.00. This is used by the municipality to pay for the operation and maintenance of the helophyte filters as well as the different sewage systems in the neighbourhood.

Each household also pays the Water Board that treats its domestic wastewater for this service (Treatment fee; Zuiveringsheffing). The amounts also differ per Water Board and how many individuals are registered in the household. As the average Dutch household has a size of 2.4 individuals the Water Boards use three tariffs; one pollution equivalent (p.e.) per household, two p.e.'s or three p.e.'s, meaning that a household consisting of three or more members will only pay for three. The Water Board Rivierenland charged €53.06 per p.e. in 2010. In the case of Lanxmeer the wastewater treatment plant of Water Board Rivierenland only treats the black wastewater, which is 29 per cent of the total amount of domestic wastewater produced (see section 6.1). Nevertheless, inhabitants of Lanxmeer get no discount on their treatment fee and have to pay the whole amount.

9.6. Functioning

9.6.1. Odour Nuisance

Since its completion there has been very little odour nuisance. Obnoxious smells are only generated when the grey wastewater has very low oxygen concentrations and comes in contact with the outside air. Sometimes noxious odours are produced when an end-cap has come off the pipe in the gravel whereby puddles of grey wastewater are produced. This is easily solved and the bad smell is not for long (Hooijer, 2010a).

Vlietstra (2010), whose office is located next to the *Station* helophyte filter, mentions that there are obnoxious smells several times every year when it rains after a long dry period, if it rains for a long time and if the temperatures increase (in spring/summer mostly). This is about three to four times per year. The smell usually lasts for a maximum of one day. This is considered manageable and the surrounding houses and offices just close the windows if it occurs. House further away from the helophyte filters do not notice the bad odours too much (Swinkels and Boland, 2010).

9.6.2. Public Health

All helophyte filters are accessible for the public. A wooden fence has been erected between the Freederik van Eemden path and the southern reed bed of the *Station* helophyte filter to prevent people who pass by (as it is a popular route when going to the train station) from entering the helophyte filter. The helophyte filter at *School* has a metal fence around it to prevent students from going there, but the helophyte filter is still accessible via the buildings. There is no fence or obstacle around the *Unie* helophyte filter. However, people living in Lanxmeer know about the helophyte filters and probably communicate their existence and purpose to their children as there have not been instances recorded where people from within the neighbourhood enter or play in the helophyte filters. There is no concern for public safety as the grey wastewater is treated in a closed system. Furthermore, the effluent of the helophyte filters, when measured, has always been of good quality (Hooijer, 2010a).

In the initial phases of the project there was some worry that the mosquito populations in the neighbourhood would increase but this has not happened (Vlietstra, 2010).

[30] For comparison, the municipality of Culemborg has a total sewage system of 165 km (Oosterom, 2011).

9.6.3. Operational Errors

Overall there have been relative few errors. The main issues after start-up were related to the pumps. If too much grey wastewater was pumped on the helophyte filters they would become too wet, thereby generating a lot of smell. If too little grey wastewater was pumped, the plants would not grow as well. This was solved by BrinkVos Water who adjusted the pumps several times till the desired situation was achieved (Hooijer, 2010a).
There have not been any issues with the piping systems in the helophyte filters or pumps apart from the end caps coming off in the helophyte filters themselves. However, this is not considered a major issue or something to take measures against (Hooijer, 2010a).

The largest unanticipated phenomenon is the amount of weeds that occur in the *Station* helophyte filter. It is unknown why these occur, but a reason could be the design of the surrounding areas. The growth of weeds and sand in the gravel do result in higher maintenance costs than first thought (Hooijer, 2010a; Swinkels and Boland, 2010).

There have been some issues with the grey wastewater sewage systems in the school buildings. Vos (2011) mentioned that the contractor had connected some toilets or urinals of a school building to the grey wastewater system. During a construction meeting this came up and it was decided that it needed to be rectified. At the next meeting, two weeks later, it was announced that this was done (which was very quick). This could not be checked, however, as the sewage pipes were covered. It was then doubted by some people if the toilets or urinals were really disconnected from the grey wastewater system but this could not be verified. Koning and Hooijer (2011) contradict this, saying that at the time that the *School* helophyte filter was constructed no school buildings were being constructed. Hence it could be that the building is confused by Vos, or that some wrong connections were made outside between sewage systems outside, instead of inside the buildings.
Koning and Hooijer (2011) mentioned that there was a connection between the black wastewater and grey wastewater sewage systems in the *VMBO* location (Ina Boudier Bakkerstraat). It was discovered in the spring of 2010 as some modifications were made to the building. This means that the grey wastewater of the *VMBO* location, which goes to the *Unie* helophyte filter, has been mixed with some black wastewater for almost two years. Although all sewage connects were supposed to be checked before the pipes were covered, this has probably not always been done. The findings at the *VMBO* location hence do not exclude the possibility that there are more faulty connections between the two sewage systems.

9.6.4. Environmental

There is no higher occurrence of flies or mosquitoes in the neighbourhood as was initially thought. Rather, there are more birds in the neighbourhood that, amongst others, are drawn to the helophyte filters (Vlietstra, 2010).
The effluent of the helophyte filters has a better quality than the average surface water quality (Hooijer, 2010a) but the quality of surface water bodies is not per se good (Swinkels and Boland, 2010). The latter case, which is close to where the effluent of the *Station* helophyte filter is discharged in a canal, could also be related to the pollution coming from the train station, people who pass by (they have been seen throwing their waste in the side of the road during fieldwork) or the fact that the canal travels under the street and parking lot for more than 100 metres.
During fieldwork a water salamander (*Lissotriton vulgaris* or *Lissotriton helveticus*) was found in the pipe through which the effluent of the *School* helophyte filter flows. The existence of such amphibians is generally related to a good quality surface water body.
It is difficult to determine what the influence of the helophyte filters on surrounding surface water bodies is as this has not been studied in this case. Overall, the ecological, sustainable and environment-friendly mind-set of the neighbourhood, as well as it being registered as an area where drinking water is extracted from the ground, results in an environment of good quality.

9.7. Performance

Although the maximum allowable hydraulic loading rate for V-SSF helophyte filters in the Netherlands is 60 $l/m^2/d$ (VROM and KIWA, 1998), the designed hydraulic loading rate in Lanxmeer is 32 $l/m^2/d$. The total daily volume of grey wastewater produced per capita was assumed to be 83 l (Bloemerts, 2011; Vos, 2011).

The design criteria were based on STOWA publication 1998-40 (Wijst and Groot-Marcus, 1998) and the guidelines as prescribed by VROM and KIWA (1998) (See section 5.3.1). The helophyte filters designed by BrinkVos Water have been accredited with the IBA Class IIIB label. Part of this label is the guarantee that the quality of the construction materials used and the effluent complies with those as prescribed by KIWA (2003) (see Table 3). The helophyte filters in Lanxmeer were guaranteed by BrinkVos Water to attain these values for five years after completion (BrinkVos Water, 2004).

The Water Board Rivierenland has given a permit to discharge effluent to surface water bodies for all three helophyte filters. The maximum allowable concentrations of the different pollutants in the effluent are given in Table 22.

Table 22. Permit regulations for effluent that is discharged to surface water bodies in Lanxmeer, Culemborg (Water Board Rivierenland, 2010)

	Units	Concentration
BOD_5	mg/l	20.0
COD	mg/l	100
N-Total	mg/l	---
TKN	mg/l	---
NO_3^-	mg/l	---
NO_2^-	mg/l	---
NH_4^+	mg/l	2.00
P-total	mg/l	3.00
TSS	mg/l	30.0
O_2	mg/l	---
pH	-	---
Temp.	ºC	---

From 2005 on the effluent of the helophyte filters has been checked once a year for compliance to the permit regulations. This is done in different seasons and at different times in order to make sure that the helophyte filters meet the required standards throughout the whole year (Table 24, Table 26 and Table 28).
Up to now all samples have been of a better quality than expected and only one case exceeded the prescribed concentrations (P-total, measured on 4-3-2009 at *Unie*, Table 28). By analysing the P-total concentrations before and after this measurement it can be concluded that this is an outlier. As the conditions in which the specific grab sample was taken are not known, the reason for this sudden increase in P in the effluent is not known.

In 2007 Vitens nv conducted a study on the performance of one helophyte filter. During one week (21-27 September) daily composite samples were collected. These composite samples consisted of aliquots taken every three hours. *E.coli* and COD were analysed from a grab sample taken every day to show the actual concentrations at a specific time period (SenterNovem, 2008). Unfortunately, it is not clear where the grey wastewater and effluent was sampled and at which helophyte filter this took place. A surface area of $1200m^2$ was mentioned leading, to the assumption that the samples were probably collected at the *Station* helophyte filter, but this is not certain. The data found in the SenterNovem report are provided in Table 23. The standard deviation of each concentration is shown behind the average of the measured concentrations. The grey wastewater characteristics shown here are also presented in Table 7 in the column "Lanxmeer".

As can be seen, BOD_5 and COD concentrations were much lower than those measured in other Dutch cases (see Table 7 as well). SenterNovem (2008) attributed this to the absence of kitchen wastewater in the grey wastewater. From interviews and documents is has not become clear that kitchen wastewater is collected with the black wastewater throughout Lanxmeer. The recorded removal of BOD and COD was more than 99 and 95 per cent, respectively.

Interestingly, N-total concentrations increased in the helophyte filter. Although NH_4^+ was removed from the wastewater, there were very high NO_3^- concentrations in the effluent. These show that denitrification processes are not common throughout the helophyte filter. The high NO_3^- are higher than the NH_4^+ concentrations in the influent indicating that degradation of organic matter, such as plant parts, could be taking place in the helophyte filter.
The P-total concentrations in the influent, measured in Lanxmeer in 2007, are well within the range measured at the other Dutch cases (Table 7). In the effluent these concentrations are still within the permit requirements even though the average removal efficiency is a little more than 55 per cent.

TSS and dissolved oxygen concentrations as well as the water temperatures were not analysed during the study. pH and *E.coli*, however, were analysed. The helophyte filter had very little influence on the pH of the grey wastewater. With 7.5 this is well within the general ranges. The measured *E.coli* concentrations were very low;[31] 300-600 cfu/100 ml. Some *E.coli* is expected to be present in the grey wastewater due to hand washing, bathing and showering. The concentrations measured in the influent in

[31] It should be noted that the SenterNovem report (2007: pp. 30) mentions that the found *E.coli* concentrations were high. The report does not mention with which standards this is compared, but it is stated that the effluent is not suitable to be used as potable water. In comparison to potable water the *E.coli* concentrations in influent and effluent were indeed high (see Table 33 in Appendix 5 for the *E.coli* concentrations in potable water provided in Lanxmeer), but this comparison is, in my opinion, not entirely correct as the effluent is discharged to surface water bodies and not used as potable water.

Lanxmeer are on the low end of the concentrations mentioned in literature describing European cases (Table 8) and lower than those found in other, international, cases (Table 9). The removal of *E.coli* varied, but it is not known what the differences were between the two measurements. Nevertheless two removal efficiencies were noted. One was almost zero, whereas the other showed a log 1.2 removal of *E.coli* pathogens from the wastewater. Although removal efficiency is quite low, the very low *E.coli* concentrations in the influent do not allow for much higher removal efficiencies; the influent concentrations are well within the standards set by the WHO for using wastewater for unrestricted irrigation ($1x10^3$ cfu/100 ml) (WHO, 2006).

Table 23. Influent, effluent and removal efficiencies measured by Vitens nv (SenterNovem, 2008)

		Units	n		*std*
BOD_5	Influent	mg/l	7	116	*47*
	Effluent	mg/l	7	<1	---
	Removal Efficiency	%		>99.1	---
COD	Influent	mg/l	7	267	*61*
	Effluent	mg/l	7	12	*1*
	Removal Efficiency	%		95.5	---
N-total	Influent	mg/l	7	11.0	---
	Effluent	mg/l	7	19.4	---
	Removal Efficiency	%		-76	---
TKN	Influent	mg/l	7	10.0	*1.7*
	Effluent	mg/l	7	0.3	*0.0*
	Removal Efficiency	%		97	---
NO_3^-	Influent	mg/l	7	<1	---
	Effluent	mg/l	7	19	*2*
	Removal Efficiency	%		A	---
NO_2^-	Influent	mg/l	7	0.01	*0.00*
	Effluent	mg/l	7	0.09	*0.03*
	Removal Efficiency	%		B	---
NH_4^+	Influent	mg/l	7	6.8	*1.8*
	Effluent	mg/l	7	<0.05	---
	Removal Efficiency	%		>99.3	---
P-total	Influent	mg/l	7	4.5	*0.5*
	Effluent	mg/l	7	2.0	*0.2*
	Removal Efficiency	%		55.6	---
TSS	Influent	mg/l	7	---	---
	Effluent	mg/l	7	---	---
	Removal Efficiency	%		---	---
O_2	Influent	mg/l	7	---	---
	Effluent	mg/l	7	---	---
pH	Influent	-	7	7.4	*0.1*
	Effluent	-	7	7.5	*0.3*
Temp.	Influent	ºC	7	---	---
	Effluent	ºC	7	---	---
E.coli	Influent	cfu/100 ml	7	$>3.0x10^3$	*0*
	Effluent	cfu/100 ml	7	$>2.75x10^3$	*0*
	Removal Efficiency	Log		0	---
E.coli	Influent	cfu/100 ml	7	$>6.0x10^3$	*0*
	Effluent	cfu/100 ml	7	$4.0x10^1$	*40*
	Removal Efficiency	Log		>1.2	---

Notes:

A: NO_3^- removal rates are negative due to the large increase in NO_3^- as the grey wastewater flowed through the helophyte filter.

B: NO_2^- removal rates are negative due to the large increase in NO_2^- as the grey wastewater flowed through the helophyte filter.

In the next three sections the performance of each V-SSF helophyte filter in Lanxmeer is discussed. The fieldwork has resulted in five removal efficiencies per pollutant per location. Initially this would have been six, but due to illness influent and effluent samples were not collected on one day (1-2-2011). As the influent sample of 31-1-2011 and effluent sample of 2-2-2011 were not of the same batch (due to the 24

hour retention time) the influent and effluent characteristics of these two days were not used to calculate removal efficiencies. Instead, they served as verification data for the other values to see if any outliers occurred and to calculate average influent and effluent pollutant concentrations (Table 34 to Table 39 in Appendices 8 to 10). No outliers have been identified.
As the daily water consumption is not known, the pollutant loads could not be calculated.

9.7.1. V-SSF Helophyte filter at *Station*

Table 24 shows the effluent characteristics measured by the Water Board to check permit compliance. As can be seen, when compared to Table 22, the concentrations have never exceeded the permit regulations. There has always been good nitrification, as there is little NH_4^+ and NO_2^- in the effluent. Denitrification has not always been very good, as the grab sample of 22-2-2007 shows. Here the NO_3^- concentrations are very high. As BOD_5 and COD concentrations are very low, this could be explained either by the lack of an anaerobic zone (as there is very good aerobic biodegradation) or the lack of enough C for the denitrifying bacteria to properly function. A combination of the two is also possible, as dissolved oxygen concentrations in the effluent were not measured. The increase in N in the effluent cannot be explained because no influent samples were taken. As grab samples taken more recently show much lower NO_3^- concentrations it could be a temporary malfunctioning of the denitrifying bacteria.

Table 24. Characteristics of effluent measured at the *Station* helophyte filter to check permit compliance (Water Board Rivierenland, 2010)

	Units	16-9-2005	27-1-2006	22-2-2007	4-3-2009	28-8-2010
n	-	1	1	1	1	1
BOD_5	mg/l	<1	<1	<1	---	---
COD	mg/l	11	13	12	---	34
N-Total	mg/l	4.5	---	23.9	---	---
TKN	mg/l	0.6	0.6	0.5	---	0.4
NO_3^-	mg/l	3.9	---	23.4	---	<0.05
NO_2^-	mg/l	<0.01	---	<0.01	---	---
NH_4^+	mg/l	<0.05	<0.05	<0.05	---	---
P-total	mg/l	0.50	0.95	0.83	**---**	0.81
TSS	mg/l	---	---	---	---	---
O_2	mg/l	---	---	---		---
pH	-	7.1	7.8	7.0	---	---
Temp.	ºC	---	---	---	---	---

Another explanation is that something containing high N concentrations (such as urine, or certain chemicals) was discarded to the grey wastewater sewage system. P concentrations in the effluent were always good. However, nothing can be said about the removal efficiencies as influent concentrations are not known.

The results of the fieldwork at the *Station* helophyte filter are presented in Table 25. Influent, effluent and removal efficiencies are given per pollutant.

The BOD_5 concentrations in the influent averaged 166 mg/l, with a standard deviation of 19 mg/l. In comparison with other Dutch cases mentioned in Table 7 this is low, although it is comparable to the earlier mentioned concentrations measured in Lanxmeer (Table 23). However, it is within the ranges found in European and international literature (Table 8 and Table 9). The COD concentrations in the influent at *Station* averaged 318 mg/l with a standard deviation of 29 mg/l/. This, again, is lower than the cases previously measured in the Netherlands and abroad with the exception of Lanxmeer (Table 23) and in Germany (Table 8). The reason for this is unknown but could be related to the possible absence of kitchen wastewater.
The average BOD_5/COD ratio of the grey wastewater is 0.5, which according to Metcalf and Eddy (2004) indicates excellent biodegradability.
The BOD_5 concentrations in the effluent are around or less than 1 mg/l. This results in a high average removal efficiency of more than 99 per cent. The COD removal efficiency is less (95 per cent), but this is because some COD can still be measured in the effluent (15 mg/l on average) as explained in section 5.2.2. Overall, these values indicate that the *Station* helophyte filter is performing well and consistent in terms of BOD and COD removal. This is in agreement with what was found previously by SenterNovem (2008).

The N concentrations in the influent at *Station* occur partly in the organic form (5.5 mg/l)[32] and partly in the NH_4^+ form (5.6 mg/l, with a standard deviation of 0.4 mg/l), indicating that people urinate in the

[32] N-total is the sum of NO_2^-, NO_3^- and TKN. TKN is the sum of NH_3, NH_4^+ and organic N.

showers and baths. The measured N-total concentrations are similar to those previously measured in Lanxmeer, but lower than those found in literature concerning other Dutch cases (Table 7). They are also similar to those found abroad (Table 8 and Table 9). On the other hand, the measured NH_4^+ concentrations are similar to those seen in Dutch and international cases, meaning that there is a variance in organic N between the cases.
The effluent contains little NH_4^+ (0.3 mg/l) and almost no NO_2^- and NO_3^-. This indicates very good nitrification and denitrification processes. The N that is present in the effluent is of the organic form. Overall, the average nitrogen removal rate was 92 per cent, with the lowest value being 87 per cent. Here the effluent of 4-2-2011 showed higher organic N concentrations, whereas the N-total concentrations in the influent of 3-2-2011 were no different from the previously measured concentrations.

Table 25. Influent and effluent characteristics and removal efficiencies of the *Station* V-SSF helophyte filter

		Units	24-1-2011-25-1-2011	25-1-2011-26-1-2011	26-1-2011-27-1-2011	2-2-2011-3-2-2011	3-2-2011-4-2-2011
BOD_5	Influent	mg/l	160	145	165	195	150
	Effluent	mg/l	1.2	<1.0	<1.0	<1.0	<1.0
	Removal Efficiency	%	99.3	>99.3	>99.4	>99.5	>99.3
COD	Influent	mg/l	295	315	295	315	315
	Effluent	mg/l	19	16	14	15	13
	Removal Efficiency	%	93.6	94.9	95.3	95.2	95.9
N-total	Influent	mg/l	10.36	10.86	11.16	11.24	11.06
	Effluent	mg/l	0.86	0.76	0.56	0.76	1.46
	Removal Efficiency	%	91.7	93.0	95.0	93.2	86.8
TKN	Influent	mg/l	10.3	10.8	11.1	11.1	11.0
	Effluent	mg/l	0.8	0.7	0.5	0.7	1.4
	Removal Efficiency	%	92.2	93.5	95.5	93.7	87.3
NO_3^-	Influent	mg/l	<0.05	<0.05	<0.05	0.13	<0.05
	Effluent	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05
	Removal Efficiency	%	>0.0	>0.0	>0.0	>61.5	>0.0
NO_2^-	Influent	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01
	Effluent	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01
	Removal Efficiency	%	>0.0	>0.0	>0.0	>0.0	>0.0
NH_4^+	Influent	mg/l	5.4	5.3	5.1	5.8	5.6
	Effluent	mg/l	0.34	0.35	0.30	0.33	0.31
	Removal Efficiency	%	93.7	93.4	94.1	94.3	94.5
P-total	Influent	mg/l	3.2	3.8	4.3	5.3	5.2
	Effluent	mg/l	0.13	0.15	0.13	0.16	0.13
	Removal Efficiency	%	95.9	96.1	97.0	97.0	97.5
TSS	Influent	mg/l	62	61	48	58	52
	Effluent	mg/l	13.0	13.0	12.0	13.0	6.6
	Removal Efficiency	%	79.0	78.7	75.0	77.6	87.3
O_2	Influent	mg/l	1.2	2.0	1.8	1.6	1.3
	Effluent	mg/l	1.5	1.5	0.9	1.8	1.2
pH	Influent	-	7.11	6.97	7.17	7.17	7.16
	Effluent	-	6.84	7.00	7.04	7.09	7.04
Temp.	Influent	ºC	9.2	9.0	8.9	8.2	8.5
	Effluent	ºC	6.3	6.0	5.5	5.7	5.6
E.coli	Influent	cfu/100 ml	9.825×10^5	1.388×10^6	1.445×10^6	2.490×10^6	1.233×10^6
	Effluent	cfu/100 ml	1.62×10^2	1.1×10^2	$<1.5 \times 10^1$	1.5×10^1	$<1.5 \times 10^1$
	Removal Efficiency	Log	3.8	4.1	>5.0	5.2	>4.9

The P-total concentrations in the influent averaged 4.5 mg/l with a standard deviation of 0.8 mg/l. This is similar to what was measured in Lanxmeer in 2007 but on the low side of the P-total ranges mentioned at the different cases (Table 7, Table 8 and Table 9). Although there is a slight increase in concentration during the sampling period this is not reflected in the effluent. Furthermore, the sampling period was too short to base any conclusions on this increase as the last measured value is decreasing again.
The effluent has an average of 0.1 mg/l P resulting in an average removal efficiency of 97 per cent. The P-total concentration measured in the effluent was low compared to the measurements done previously by Vitens nv (Table 23) and the Water Board (Table 24). As different processes at different scales are responsible form removing P from the wastewater this difference is difficult to explain. Perhaps the rate

or scale of processes such as peat/soil accumulation, adsorption to soil particles or precipitation has seen a sudden increase.

TSS concentrations averaged 58 mg/l during the sampling period. This is similar to the concentrations measured in Groningen (Table 7) but low compared to the international cases (Table 8 and Table 9).
The TSS removal efficiencies were lower than the removal efficiencies of the other pollutants; 79 per cent. This average value is relatively high as the removal efficiency of 3-2-2011 – 4-2-2011 was quite high (87 per cent as opposed to 77 per cent). Interestingly, on 4-2-2011 the TSS concentrations were half of the other samples (6.6 mg/l opposed to 13 mg/l). As all samples analysed were composite samples the low concentration cannot be attributed to the occurrence of an outlier as is the case with a grab sample. As the effluent was collected in the same manner each time from the same pumping tank the chances of this happening are lessened even more. There is no decline in effluent TSS concentration during the whole sampling period and the low value is the last measured concentration which complicates the matter even more.

Dissolved oxygen concentrations in influent are not exceptionally low (1.6 mg/l; standard deviation is 0.7 mg/l), thereby allowing for biodegradation in the pumping tank. Observations in dissolved oxygen concentrations made during the day showed that this was happening. This is also made clear by Figure 17.

The average dissolved oxygen concentrations are a bit lower in the effluent (1.4 mg/l; standard deviation is 0.4 mg/l), but not completely zero. Also, the relative high standard deviation, the values recorded in Table 25 as well as those presented in Appendices 11 and 12 show there is a variance in the measured dissolved oxygen concentration in both influent and effluent. This can be ascribed to the biodegradation taking place in the pumping tank as well as turbulence caused when grey wastewater flows into this tank. The variance in the effluent could be explained by extent to which biodegradation takes place in the helophyte filter and how much the wastewater is exposed to oxygen in the helophyte filter.

The grey wastewater at *Station* has an average pH of 7.13 with a standard deviation of 0.09. This neutral value was expected as the wastewater from different household sources that produce the grey wastewater is mixed in the pumping tank. Furthermore, the composite sample that was formed for the analysis also aids in an averaging of the pH. Because the majority of the wastewater sources in a household produce wastewater with a relative neutral pH, the effects of household activities that can produce wastewater with a more extreme pH, such as laundry wastewater, become less relevant. It should be noted that the pH of the potable water provided to the neighbourhood by Vitens nv during the sampling period was 7.9 (see Appendix 7).
The pH is not affected much by the helophyte filter; there is a slight decrease to an average of 7.02, which could be ascribed to the general pH of the medium as well as the chemical reactions taking place.

The average temperature of the influent is 8.7 ºC with a standard deviation of 0.5 ºC. As the influent flowed through the helophyte filter it cooled down to an average of 5.7 ºC. Even though the outside temperatures ranged between -3.1 and 10.1 ºC (see Table 32, Appendix 6) while samples were being collected and in the weekend temperatures dropped to -6.4 ºC the influent was warm enough to ensure that bacterial activity remained as the grey wastewater flowed through the helophyte filter. When comparing Table 44 and Table 45 in Appendix 11 with the climate data from Appendix 6 the influence of the outside temperatures becomes clear. As the outside temperatures decreased or increased, the influent and effluent temperatures decreased or increased as well. The measured effluent temperatures never dropped below 4.9 ºC, which is warm enough for the bacteria to survive.
The measured grey wastewater temperatures are lower than those found in literature (Table 7, Table 8 and Table 9), but this can be ascribed to the cold weather when the samples were taken.

The *E.coli* concentrations that were found in the grey wastewater at *Station* were higher than expected ($1.4x10^5$ cfu/100 ml with a standard deviation of $5.4x10^4$ cfu/100 ml), especially when they are compared to the *E.coli* concentrations that were measured in Lanxmeer in 2007 (Table 23). This is on the high side but within the range of *E.coli* concentrations measured at European and other international cases. These high *E.coli* concentrations also occur at the other two helophyte filters (Table 27 and Table 29), leading to the conclusion that this concentration could be representative of the neighbourhood. However, it is not clear how this relates to the earlier *E.coli* concentrations measured. It could be that the shower, bath and perhaps sinks in the toilets are responsible for more pathogens in the wastewater than is thought. Another possibility is that people have made modifications to their homes, resulting in faulty sewage connections where some homes now discharge the black wastewater into the grey wastewater system. The scale at which this has happened should not be too large as the COD and NH_4^+ concentrations are lower than expected. The use of washable instead of disposable nappies could also be an explanation although if this were the case the number of inhabitants using these nappies should be spread equally throughout the neighbourhood as the other two locations also show high *E.coli* concentrations. This is not plausible and the first two explanations seem the most likely.

The *E.coli* concentrations in effluent are very low (59 cfu/100 ml). However, there is a high variance in the concentrations as the high standard deviation (62 cfu/100 ml) and values in Table 25 show. As the processes by which *E.coli* is removed from the wastewater are mainly biological (section 5.2.2) climate factors (rain, irradiation, etc.) can influence the removal rates and thus partly explain the variance. Another explanation is that the die off rates of the pathogens is not fixed and hence some could survive for a longer time. The high removal efficiency (an average of log 4.8) shows that the high *E.coli* concentrations present in the influent are effectively removed by the helophyte filter in colder temperatures.[33] The effluent is suitable for unrestricted irrigation, according to WHO standards (see section 5.2.2) (WHO, 2006).

Overall, the *Station* helophyte filter showed excellent removal efficiencies during the sampling period. The low BOD_5, COD and dissolved oxygen concentrations of the effluent indicate that the biodegradation is either finishing or completely done. Also, nitrification and denitrification processes are completed as the low NH_4^+, NO_2^- and NO_3^- effluent concentrations show. If the helophyte filter analysed in 2007 was the *Station* helophyte filter it is interesting to note that the NO_3^- concentrations in the effluent, which were high in 2007, were low in 2011. This could indicate that the occurrence of denitrification processes is not a given fact in a V-SSF helophyte filter or that external factors influence the amount of NO_3^- that needs to be removed from the water in the helophyte filter (e.g. decomposition of dead plant material). *E.coli* concentrations are also lowered to satisfactory concentrations. An overall better treatment of the grey wastewater at *Station* will be difficult to realise except when some specific pollutants such as organic N and P would be removed even more extensively. However, when taking the future purpose of the effluent into account, which is discharge to a surface water body, it is the doubtful if extensive removal of these pollutants is necessary.

9.7.2. V-SSF Helophyte filter at *School*

Table 26 shows the results of the annual checks that the Water Board Rivierenland performed to ensure that the effluent of the *School* helophyte filter complied with the permit to discharge effluent to surface water bodies. Similar to the *Station* helophyte filter the permit regulations have never been exceeded. N-total concentrations are always low, as opposed to the *Station* helophyte filter where NO_3^- concentrations had a peak on 22-2-2007. Based on the grab samples from the *School* helophyte filter with low NH_4^+ concentrations, one can conclude that the nitrification and denitrification processes are both taking place. There is more variance in the P-total concentrations compared to the *Station* helophyte filter, but the concentrations are always well within those dictated by the permit (Table 22).

Table 26. Characteristics of effluent measured at the *School* helophyte filter to check permit compliance (Water Board Rivierenland, 2010)

	Units	16-9-2005	27-1-2006	22-2-2007	4-3-2009	28-8-2010
n	-	1	1	1	1	1
BOD_5	mg/l	<1	<1	<1	---	---
COD	mg/l	10	11	11	15	18
N-Total	mg/l	2.5	---	4.0	---	---
TKN	mg/l	0.5	0.5	0.6	0.7	0.5
NO_3^-	mg/l	1.9	---	3.4	---	1.4
NO_2^-	mg/l	<0.01	---	<0.01	---	---
NH_4^+	mg/l	<0.05	<0.05	<0.05	---	---
P-total	mg/l	0.40	1.30	0.60	0.77	0.26
TSS	mg/l	---	---	---	---	---
O_2	mg/l	---	---	---		---
pH	-	7.0	7.7	7.3	---	---
Temp.	ºC	---	---	---	---	---

As the high P concentrations occur in cold months, and low P concentrations in warmer months, it could be possible that the climate (temperature, precipitation) has an effect on the removal of P from wastewater or the release of P from the helophyte filter. This, however, cannot be concluded from the data in Table 26 as they are merely grab samples and the values could be outliers. Also, this trend is not seen as clearly at the *Station* helophyte filter and very roughly at the *Unie* helophyte filter.

The results of the fieldwork at the *Station* helophyte filter are presented in Table 27. Influent, effluent and removal efficiencies are given per pollutant.

[33] A side note here is that it would be interesting to see if this is the same during the summer as pathogens favour moderate temperatures.

The average BOD_5 concentrations measured in the influent at the *School* helophyte filter were, compared to the Dutch, European and other international figures found in literature (Table 7, Table 8 and Table 9), low; 180 mg/l with a standard deviation of 17 mg/l. The same goes for the COD concentrations (334 mg/l, standard deviation was 18 mg/l). Both concentrations were a bit higher than was previously found in Lanxmeer (Table 23). Lower BOD_5 and COD concentrations were expected as a relative large fraction of the wastewater originates in the school. Here no laundry activities were expected, and little, shower wastewater production as the students hardly ever shower (Koning and Hooijer, 2011). There is a cafeteria in three of the four school buildings (none in *Junior High* location) although these are not used intensively. However, there are kitchens in the staff rooms that are used intensively. The janitor noted that these dishwashers are used continually by the staff. These could be responsible for higher BOD_5 and COD concentrations than expected, although the influence of dishwashers can be debated. On the other hand, SenterNovem (2008) notes that the kitchen was not a source for grey wastewater during their study. Although their sampling location could have been different, it does show that there are a lot of unknowns about the source of grey wastewater.
The BOD_5/COD ratio is 0.5, indicating that the grey wastewater has good biodegradability potential (Metcalf and Eddy, 2004).
The average BOD_5 concentrations in the effluent were less than 0.9 mg/l (standard deviation of 0.4 mg/l), and the average COD concentrations were 13 mg/l (standard deviation of 2 mg/l), both indicating that good biodegradation is taking place. The average removal efficiencies recorded were 99 per cent and 96 per cent, respectively. The high dissolved oxygen concentrations in the effluent also indicate that biodegradation is completed by the time that the effluent leaves the helophyte filter.

The N-total concentrations in the grey wastewater at *School* were, compared to the cases shown in Table 7, Table 8 and Table 9, very high (24.2 mg/l). Although more extreme cases were measured in Sneek (Hernández Leal *et al*., 2007; Zeeman *et al*., 2008) and Israel (Gross *et al*., 2007) these are also exceptions in the Tables. The N concentrations in the influent were also twice as high as the N concentrations measured at the *School* and *Unie* helophyte filters. These high N concentrations mainly occur in the form of NH_4^+ (17.1 mg/l with a standard deviation of 4.7 mg/l). These unusual high concentrations can only originate in urine, leading to the conclusion that either the students urinate while taking a shower (which they do not take often at the school) or that some toilets or urinals have been connected to the grey wastewater sewage system instead of the black wastewater sewage system as was the case at the *VMBO* location (see section 9.6). The BOD_5 and COD concentrations, which were higher than expected, can also be explained this way. The latter two are not as high as those found in domestic wastewater as not all toilets in the school could be connected to the grey wastewater system.

The effluent of the *School* helophyte filter has low NH_4^+ and NO_2^- concentrations (0.32 mg/l and 0.02 mg/l, respectively), but relative high NO_3^- concentrations (11.7 mg/l). Note that these concentrations are still lower than those measured in Lanxmeer in 2007 (Table 23). This indicates that there are nitrification processes, but no, or very little, denitrification processes. This can be explained by the absence of an anaerobic zone, the absence of enough C or very low temperatures (less than 5 ºC) (Vymazal and Kröpfelová, 2008). As only 50 per cent of the designed hydraulic load is applied on this helophyte filter (construction of houses is still going on) it is possible that not enough water is present in the helophyte filter to allow for the formation of anaerobic zones. Another possibility is that all C (in the form of biodegradable matter) is removed from the wastewater in the top layers of the substrate. This is indicated by the low BOD_5 and COD concentrations in the effluent. These top layers in the substrate are mainly aerobic as air is drawn into these layers when the influent percolates downward. Then, when the wastewater reaches anaerobic zones, there is not enough C left in the wastewater for denitrification processes. In comparison, the *Unie* helophyte filter also receives only half of its design load but still has enough denitrification processes to remove almost all NO_3^-. It thus seems that there is enough C in the wastewater when it reaches anaerobic zones to denitrify the little amount of NO_3^- that is usually present at this point, but not enough C to denitrify the amount of NO_3^- that is present in the wastewater at the *School* helophyte filter.
Controversially, the grab samples taken by the Water Board for their annual checks do not show high NO_3^- concentrations (Table 26). This could mean that denitrification has been taking place in the past and that the current lack of denitrification could be temporarily. Another possibility is that the sewage systems in the school were constructed properly, but that more recent construction works on houses have resulted in some faulty sewage connections meaning that the problems have started more recently.

The average P-total concentration in the influent is 3.8 mg/l with a standard deviation of 0.5 mg/l. Compared to the cases found in European and international literature (Table 8 and Table 9) this is very low. It is within the ranges, but on the low side, of the P-total concentrations mentioned at the Dutch cases (Table 7) and as seen previously in Lanxmeer (Table 23). As explained earlier, the explanation for these low concentrations is the absence of P in laundry detergents.
The average removal efficiency was 70 per cent, with P-total concentrations averaging 1.2 mg/l in the effluent. This is a ten-fold higher than the effluent concentrations at the *Station* helophyte filter, which on the other hand were low. The P-total concentrations of the effluent at *School* are still within the permit regulations and lower than those previously measured in Lanxmeer (Table 23). This concentration

is similar to that measured by the Water Board in the winter months. However, the grab samples collected by the Water Board during summer months show lower P-total concentrations, which perhaps is an indication that P is more efficiently removed in warmer climates.

Table 27. Influent and effluent characteristics and removal efficiencies of the *School* V-SSF helophyte filter

		Units	24-1-2011-25-1-2011	25-1-2011-26-1-2011	26-1-2011-27-1-2011	2-2-2011-3-2-2011	3-2-2011-4-2-2011
BOD_5	Influent	mg/l	185	155	205	185	170
	Effluent	mg/l	<1.0	<1.0	<1.0	<0.1	<1.0
	Removal Efficiency	%	>99.5	>99.4	>99.5	>99.9	>99.4
COD	Influent	mg/l	335	320	340	315	330
	Effluent	mg/l	11	13	12	13	17
	Removal Efficiency	%	96.7	95.9	96.5	95.9	94.8
N-total	Influent	mg/l	22.06	22.06	22.06	31.07	28.06
	Effluent	mg/l	12.62	10.72	11.42	13.23	13.21
	Removal Efficiency	%	42.8	51.4	48.2	57.4	52.9
TKN	Influent	mg/l	22.0	22.0	22.0	31.0	28.0
	Effluent	mg/l	0.8	0.7	0.6	0.7	<0.1
	Removal Efficiency	%	96.4	96.8	97.3	97.7	>99.6
NO_3^-	Influent	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05
	Effluent	mg/l	11.8	10.0	10.8	12.5	13.1
	Removal Efficiency	%	A	A	A	A	A
NO_2^-	Influent	mg/l	<0.01	<0.01	<0.01	0.02	0.01
	Effluent	mg/l	0.02	0.02	0.02	0.03	<0.01
	Removal Efficiency	%	B	B	B	B	>0.0
NH_4^+	Influent	mg/l	15.6	20.9	12.0	23.0	19.5
	Effluent	mg/l	0.51	0.60	0.46	0.14	0.06
	Removal Efficiency	%	96.7	97.1	96.2	99.4	99.7
P-total	Influent	mg/l	3.6	3.4	3.6	4.8	4.0
	Effluent	mg/l	1.0	1.0	1.1	1.4	1.3
	Removal Efficiency	%	72.2	70.6	69.4	70.8	67.5
TSS	Influent	mg/l	57	59	52	61	53
	Effluent	mg/l	<2	<2	<2	<2	<2
	Removal Efficiency	%	>96.5	>96.6	>96.2	>96.7	>96.2
O_2	Influent	mg/l	0.5	1.0	1.0	1.2	1.1
	Effluent	mg/l	5.6	4.7	5.0	6.1	6.5
pH	Influent	-	7.07	6.98	7.10	7.35	7.29
	Effluent	-	6.77	6.86	6.87	7.04	6.98
Temp.	Influent	ºC	11.9	11.3	10.8	10.5	11.4
	Effluent	ºC	7.5	7.1	6.5	6.1	6.4
E.coli	Influent	cfu/100 ml	$1.57x10^6$	$1.388x10^6$	$5.175x10^5$	$7.025x10^5$	$6.3x10^5$
	Effluent	cfu/100 ml	$5.19x10^2$	$5.49x10^2$	$5.56x10^2$	$2.15x10^3$	$3.9x10^2$
	Removal Efficiency	Log	3.5	3.4	3.0	2.5	3.2

Notes:

A: NO_3^- removal rates are negative due to the large increase in NO_3^- as the grey wastewater flowed through the helophyte filter.

B: NO_2^- removal rates are negative due to the large increase in NO_2^- as the grey wastewater flowed through the helophyte filter.

The average TSS concentration is 58 mg/l with a standard deviation of 4 mg/l. This is similar to the influent at *Station* and the concentrations measured in Groningen (Table 7) but low compared to the international cases (Table 8 and Table 9).
The average TSS removal efficiencies were higher at *School* than at *Station* (96 per cent). Why the effluent had such low TSS concentrations (less than 2 mg/l) is not known, but it could be related to the lower hydraulic load that the helophyte filter has to treat. As a consequence fewer solids accumulate in the helophyte filter, resulting in better prolonged filtration.

The dissolved oxygen had an average concentration of 0.9 mg/l with a standard deviation of 0.4 mg/l. This relative high standard deviation can also be seen in Figure 17, where the measured dissolved oxygen concentrations ranged from 0.6 mg/l to 1.8 mg/l. The reason this variance occurs is because of the biodegradation that starts in the pumping tanks. This can be seen in the declining curve in Figure 17.

As the grey wastewater coming into the pumping tank contains higher dissolved oxygen concentrations than the grey wastewater already in the pumping tank, a peak in the dissolved oxygen concentration is measured when there is inflow. When the pumping tank is almost full the higher oxygen concentration in the inflow will have less effect than when the pumping tank is almost empty. Hence the peak in the curve shows where grey wastewater flows into the pumping tanks after it has been emptied by the pumps.
The high effluent concentrations (5.6 mg/l) show that there is a large increase in dissolved oxygen concentration. It is not clear why the standard deviation is relatively large (1 mg/l). It could be that the eddies observed in the effluent flow results in this variance. Nevertheless, the overall dissolved oxygen concentrations show that the biodegradation is completed, resulting in low BOD_5 and COD concentrations, and that at the same time oxygenation is taking place in the helophyte filter. This high oxygenation rate could be the reason that there is little to no denitrification.

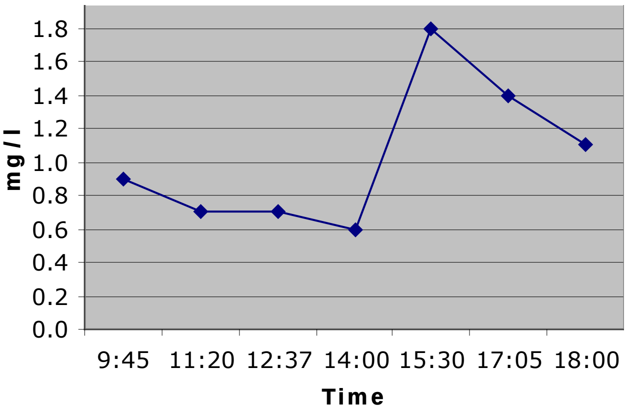


Figure 17. Dissolved oxygen concentrations measured at *School* during one day (26-1-2011)

The grey wastewater at *School* had an average pH of 7.15, which is similar to the Dutch, European and international cases (Table 7, Table 8 and Table 9) as well as the grey wastewater measured at *Station.* It is a bit lower than those previously measured in Lanxmeer in 2007, which were around 7.4 (Table 23).
The pH was affected a little by the helophyte filter as it was 6.93 on average in the effluent. This could be because of the pH of the substrate as well as the chemical reactions taking place in the helophyte filter.

The influent temperatures were, as at *Station*, influenced by the climate with the values being lower when it was colder outside. Nevertheless, during the two weeks of measurements the grey wastewater in the pumping tank had an average temperature of 11.2 °C with a standard deviation of 0.6 °C. This is warmer than the grey wastewater at *Station* but this can be explained by the shorter distance that the grey wastewater has to travel before it reaches the pumping tank. Another influence is the depth of the pumping tank; the one at *School* was almost twice as deep, thereby lessening the influence of the air temperatures.
As the grey wastewater flowed through the helophyte filter it cooled down to an average 6.4 °C, with the lowest measured value being 5.0 °C. This is enough to sustain bacterial activity.

The *E.coli* concentrations were, like at *Station*, higher than expected. The grey wastewater had an average *E.coli* concentration of 9.7×10^5 cfu/100 ml. This is higher than those measured previously in Lanxmeer (Table 23) and at *Station* and on the high end of the values found in literature (Table 7, Table 8 and Table 9). On the other hand, they are a lower than those found in grey wastewater at *Unie*. Assuming that some toilets are connected to the grey wastewater sewage system it would be expected that the *E.coli* concentrations would be higher than those measured now.
As the effluent shows, the helophyte filter is capable of removing the *E.coli* from the grey wastewater with a reduction of log 3.1 (9.3×10^2 cfu/100 ml with a standard deviation of 7×10^2 cfu/100 ml). An explanation could be that the higher levels of dissolved oxygen in the effluent, which can increase the survival rates. Although the *E.coli* concentrations are not as low as at *Station*, the average measured concentrations fulfil WHO criteria for being used for unrestricted irrigation (see section 5.2.2) (WHO, 2006). It should be noted that the effluent of 2-2-2011 and 3-2-2011 contains too many *E.coli*, meaning that the effluent is on the edge of being acceptable (see Table 37 in Appendix 9).

Overall the helophyte filter at *School* has good removal efficiencies. There are, however, a few side notes. The effluent shows relative high NO_3^+ concentrations as there is very little denitrification. There are also relative high P-total and *E.coli* concentrations in the effluent. Although the P-total concentrations are well within the permit regulations, the *E.coli* concentrations are close to the maximum concentrations acceptable for unrestricted irrigation. This, in Lanxmeer, should not be a problem as the surface water is not used by the public for any purpose and they normally do not come in contact with it. Furthermore, the water body that the effluent is discharged to could also be polluted by the faeces of water birds such as ducks. Lastly, there will also be natural die-off of the *E.coli* after it leaves the helophyte filter. These lessen the influence of the (high) *E.coli* concentrations coming from the helophyte filter and hence the threat it poses to public health.

The high NH_4^+, BOD_5 and COD concentrations can be explained by the connection of some toilets or urinals to the grey wastewater system. However, the *E.coli* concentrations do not immediately point out that some toilets are connected to the grey wastewater system, leading to the conclusion that perhaps some urinals are connected to the grey wastewater sewage system. This would explain the high NH_4^+ concentrations. The higher-than-expected BOD_5 and COD concentrations can also originate in kitchen wastewater.

9.7.3. V-SSF Helophyte filter at *Unie*

The results of the annual checks that the Water Board Rivierenland performed at the *Unie* helophyte filter are shown in Table 28.

As can be seen, the BOD_5 and COD concentrations have always been low and well within the permit regulations. There is a bit of fluctuation in the COD concentrations, but as these checks were performed with grab samples no conclusions can be drawn. The recorded N concentrations in the effluent have been low with a small peak in NO_3^- on 16-9-2005. The low NH_4^+, NO_2^- and NO_3^- concentrations show that nitrification and denitrification processes are taking place. When looking at the P-total concentrations measured from 2005 to 2009 one could conclude, were it not that the data came from grab samples, that the *Unie* helophyte filter was increasingly becoming more saturated with P. On 4-3-2009 the P-total concentrations exceeded the permit regulations. However, as this exceedance was very little no actions were taken. The next grab sample showed much lower P-total concentrations, which are comparable to the other two helophyte filters.

Table 28. Effluent measured at the *Unie* helophyte filter to check permit compliance (Water Board Rivierenland, 2010)

	Units	16-9-2005	27-1-2006	22-2-2007	4-3-2009	28-8-2010
n	-	1	1	1	1	1
BOD_5	mg/l	<1	<1	<1	---	---
COD	mg/l	22	16	13	18	<10
N-Total	mg/l	5.9	---	1.6	---	---
TKN	mg/l	0.6	2.1	0.6	<0.5	-0.1
NO_3^-	mg/l	5.3	---	1.0	---	0.2
NO_2^-	mg/l	<0.01	---	<0.01	---	---
NH_4^+	mg/l	<0.05	0.17	<0.05	---	---
P-total	mg/l	0.33	0.63	1.80	**3.10**	0.55
TSS	mg/l	---	---	---	---	---
O_2	mg/l	---	---	---		---
pH	-	7.1	7.8	7.0	---	---
Temp.	ºC	---	---	---	---	---

Table 28 shows the chararcteristics of the infleunt and corresponding effluent samples collected at *Unie* during the fieldwork.

The average BOD_5 concentration of the grey wastewater at *Unie* was 123 mg/l with a standard deviation of 16 mg/l. This is very low compared to the other two cases as well as the Dutch, European and international BOD_5 concentrations that were found in literature (Table 7, Table 8 and Table 9). However, it is comparable to the concentrations measured by Vitens nv in Lanxmeer (Table 23). The same goes for the average COD concentration that was measured (256 mg/l with a standard deviation of 26 mg/l). These low concentrations can be explained by the sources of the grey wastewater. These are houses, offices and a school building. As the latter two produce no laundry wastewater, little shower wastewater and less kitchen wastewater compared to a household the BOD_5 and COD concentrations were expected to be lower than those of grey wastewater only originating in households.
The BOD_5/COD ratio of the influent was 0.48, which is a bit lower than the other two cases but still indicated good potential biodegradation.
With average removal efficiencies of 98 per cent and 91 per cent for BOD_5 and COD, respectively, the effluent concentrations were 1.9 mg/l and 24 mg/l, respectively. Interestingly, although the BOD_5 and COD concentrations are lower in the influent of *Unie* than the other two cases, the concentrations are higher in the effluent of *Unie*. As the dissolved oxygen concentrations in the effluent are 4.8 mg/l, the biodegradation is assumed to be completed. The high COD concentrations can be explained by the reaction of other, non-biodegradable substances with the dichromate in an acid solution used during the COD analysis. These compounds could originate in the chemicals used to clean the offices and school.

The N in the influent is in the NH_4^+ form (3.3 mg/l, on average, with a standard deviation of 0.5 mg/l) and organic N form (4.8 mg/l). These concentrations are lower than those found in both Dutch and European literature (Table 7 and Table 8). There are some international cases (e.g. Jordan) that report similar N-total concentrations, but the sources of this N are not known (Table 9).
Although the removal efficiencies are lower than those recorded at *Station* and *School* (82 per cent for N-total, on average), the effluent still complies with the permit regulations. The effluent has very low NO_2^-

and NO_3^- concentrations (0.01 mg/l and 0.06 mg/l, respectively), indicating good nitrification and denitrification processes. NH_4^+ concentrations are higher than at the other locations (0.83 mg/l), which is the reason for the lower N-total removal efficiencies. It is difficult to clearly state why the ammonification processes at *Unie* are less than at the other two locations.

The average P-total concentration in grey wastewater at *Unie* is 5.6 mg/l with a standard deviation of 0.3 mg/l. This is higher than the other two cases but well within the range of figures mentioned by Dutch and European literature (Table 7 and Table 8). As expected it is lower than international cases from outside Europe due to the use of laundry detergents containing P (Table 9). This high P concentration in the influent can originate in kitchen wastewater. As the offices and school could use dishwashers to clean dishes, such as coffee mugs, but do not prepare food in the kitchens the wastewater can contain relative high concentrations of dishwashing detergents. These detergents are a major P source.
The P-total concentration in the effluent is an average of 1.1 mg/l with a standard deviation of 0.1 mg/l. This is similar to the effluent of the *School* helophyte filter, lower than the concentration measured in 2007 (Table 23) but a ten-fold higher than that of the *Station* helophyte filter. The average removal efficiency of 80 per cent is higher than *School*, but lower than *Station*. Overall, the P-total concentrations in the effluent do not indicate that the helophyte filter is saturated with P and instead suggest that the high value recorded in 2009 by the Water Board was an outlier.

Table 29. Influent and effluent characteristics and removal efficiencies of the *Unie* V-SSF helophyte filter

		Units	24-1-2011-25-1-2011	25-1-2011-26-1-2011	26-1-2011-27-1-2011	2-2-2011-3-2-2011	3-2-2011-4-2-2011
BOD_5	Influent	mg/l	135	97	110	125	130
	Effluent	mg/l	2.4	2.2	1.6	1.4	1.6
	Removal Efficiency	%	98.2	97.7	98.5	98.9	98.8
COD	Influent	mg/l	275	220	235	245	285
	Effluent	mg/l	27	24	22	25	20
	Removal Efficiency	%	90.2	89.1	90.6	89.8	93.0
N-total	Influent	mg/l	7.56	7.46	6.86	9.21	8.26
	Effluent	mg/l	1.42	1.36	1.36	1.46	1.48
	Removal Efficiency	%	81.2	81.8	80.2	84.1	82.1
TKN	Influent	mg/l	7.5	7.4	6.8	8.4	8.2
	Effluent	mg/l	1.3	1.3	1.3	1.4	1.4
	Removal Efficiency	%	82.7	82.4	80.9	83.3	82.9
NO_3^-	Influent	mg/l	<0.05	<0.05	<0.05	0.80	<0.05
	Effluent	mg/l	0.11	<0.05	<0.05	<0.05	0.07
	Removal Efficiency	%	[A]	>0.0	>0.0	>93.8	[A]
NO_2^-	Influent	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01
	Effluent	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01
	Removal Efficiency	%	>0.0	>0.0	>0.0	>0.0	>0.0
NH_4^+	Influent	mg/l	2.9	3.0	2.6	3.5	3.5
	Effluent	mg/l	0.68	0.81	0.87	0.86	0.87
	Removal Efficiency	%	76.6	73.0	66.5	75.4	75.1
P-total	Influent	mg/l	5.1	6.1	5.6	5.3	5.7
	Effluent	mg/l	1.0	1.0	1.0	1.2	1.2
	Removal Efficiency	%	80.4	83.6	82.1	77.4	78.9
TSS	Influent	mg/l	45	61	36	44	49
	Effluent	mg/l	34	28	29	32	30
	Removal Efficiency	%	24.4	54.1	19.4	27.3	38.8
O_2	Influent	mg/l	3.8	4.1	4.0	2.9	3.2
	Effluent	mg/l	5.0	4.9	3.9	5.1	5.0
pH	Influent	-	7.21	7.19	7.28	7.33	7.27
	Effluent	-	7.09	7.21	7.03	7.25	7.12
Temp.	Influent	ºC	10.2	9.3	9.4	9.3	9.9
	Effluent	ºC	6.3	6.0	5.5	5.5	5.6
E.coli	Influent	cfu/100 ml	$1.79x10^6$	$1.388x10^6$	$1.79x10^6$	$3.18x10^6$	$2.49x10^6$
	Effluent	cfu/100 ml	$1.114x10^3$	$8.72x10^2$	$9.81x10^2$	$6.35x10^2$	$6.9x10^2$
	Removal Efficiency	Log	3.2	3.2	3.3	3.7	3.6

Notes:

A: NO_3^- removal rates are negative due to the large increase in NO_3^- as the greywastewater flowed through the helophyte filter.

The TSS concentrations are low (46 mg/l on average with a standard deviation of 9 mg/l). This is lower than the two other cases as well as the cases shown in Table 7, Table 8 and Table 9 and can be explained by the offices and school, which produce less kitchen wastewater and very little shower wastewater.
Surprisingly, the effluent of the *Unie* helophyte filter has high TSS concentrations (31 mg/l). This could also be seen at the outflow point, where a lot of ochre-coloured solids had accumulated (Figure 18). The effluent itself also was this colour. The source of this colour was unknown, but could be related to the substrate material of the helophyte filter. An explanation could be that ferrous iron (Fe^{2+}) is leaching from the helophyte filter. It should be noted that the TSS concentrations of the effluent at *Unie* are at the maximum limits (30 mg/l) as set by the permit (Table 22).

Figure 18. Outflow point at *Unie* helophyte filter. Notice the ochre colour

The average dissolved oxygen concentration in the influent during the sample collection period was 3.5 mg/l with a standard deviation of 0.6 mg/l. Although the concentrations are higher than the other two cases, the same trend as in Figure 17 was seen (see also Appendix 16). The relative high dissolved oxygen content can be explained by the different sources of the grey wastewater and perhaps the construction of the pumping tank. As the grey wastewater pours into the tank a lot of turbulence is created. The latter, however, seemed not to be different from the other pumping tanks. The lower BOD and COD concentrations could also mean that the biodegradation is taking place at a slower rate than the other locates, meaning that less dissolved oxygen is consumed per time unit.
The average dissolved oxygen concentration in the effluent water was 4.8 mg/l, with a standard deviation of 0.6 mg/l. This high dissolved oxygen concentration supports the conclusion that the biodegradation processes have been completed but that the measured COD concentrations in the effluent are other pollutants that reacted to the dichromate and acid. It is interesting to note that even though the influent and effluent have substantial dissolved oxygen concentrations, there is very little NO_3^- in the effluent. This means that there are anaerobic zones in the helophyte filter where the denitrification can occur, and that there are other zones, after the anaerobic ones, where oxygenation takes place.

The pH of the influent is similar to the other cases (7.26 with a standard deviation of 0.07). It is on the high side of the mentioned Dutch cases (Table 7), but well within the ranges mentioned in Table 8 and Table 9. The pH of the potable water supplied during the sampling period was 7.9 (Table 33, Appendix 7). As little household activities occur in the offices and school there are less inputs in the grey wastewater that can lower the pH.
The pH is lowered a bit as the grey wastewater flows through the helophyte filter. The average pH measured was 7.16 (standard deviation of 0.12). This is slightly higher than the pH of the effluent at *Station* and *School*, and can be attributed to the pH of the influent, the medium used in the helophyte filter and the chemicals used to clean the offices and school.

The temperature of the grey wastewater changes with the air temperatures, like at the other two helophyte filters. During the sampling period the average temperature of the grey wastewater was 9.7 ºC, which is lower than at *School* but higher than at *Station*. An explanation for this could be that the pumping tank, like at *School*, is deeper than the one at *Station*, but that the grey wastewater has to travel a longer distance from the offices, school and houses before it reaches the pumping tank. In the sewage system some warmth is lost.
In the helophyte filter the average temperature is lowered to 5.6 ºC, with the lowest recorded value being 4.8 ºC. Although this is on the edge of allowing proper bacterial functioning and denitrification processes it only lasted for a short while, as can be seen in Table 91 (Appendix 16). As the effluent concentrations in Table 28 show no negative effects have been measured.

E.coli concentrations were higher than expected. With an average concentration of $2.1x10^6$ cfu/100 ml it is the highest of all cases (standard deviation was $6.4x10^5$ cfu/100 ml). These concentrations, according to Metcalf and Eddy (2004), are usually found in medium to highly concentrated wastewater (Table 6). The concentrations are similar to those recorded in literature about international cases (Table 9), but on the high end of the European cases mentioned (Table 8).
The average reduction of log 3.4 resulted in an average *E.coli* concentration of $8.7x10^2$ cfu/100 ml (standard deviation was $1.8x10^2$ cfu/100 ml). Although this is lower than the average concentration at *School*, the highest measured concentration was $1.1x10^3$ cfu/100 ml, which is slightly higher than the WHO guideline values recommend for unrestricted irrigation. This, like at *School*, should however not pose much of a health threat as the surface water to which the effluent is discharged is not used for any other purpose, people generally do not come in contact with this water and there is a natural die-off of

the pathogens in the surface water. Furthermore, the faeces of water birds such as ducks pollute these water bodies as well, thereby lessening the influence of the pathogens in the effluent.

It is unclear why the pollutant concentrations measured in the effluent at *Unie* are higher than the other locations, whereas certain pollutants such as BOD, COD and N are lower in the influent. Furthermore, the high concentrations of *E.coli* in the influent are also not understood as the grey wastewater originates in offices, a school building and households. This means that less wastewater should be coming from the showers and baths (which is the main source of pathogens in grey wastewater). The low COD and NH_4^+ concentrations indicate that a faulty connection between toilets or urinals and the grey wastewater sewage system is unlikely, although this cannot be excluded as previous experiences with the school building have shown (see section 9.6)

9.8. Perception, Future and Recommendations

9.8.1. Perception

The helophyte filter is described in an information booklet that all inhabitants get when they move into the neighbourhood, as well as an A5-sized information card that can be put on the refrigerator (BEL, 2003; Swinkels and Boland, 2010). On this information card a schematic overview of the helophyte filter similar to Figure 19 is depicted as well as a list of which chemicals should not be flushed down the sink (see text box below). These chemicals can be discarded in Small Chemical Waste containers that all households in the Netherlands have. It is not known if these chemicals are all discarded this way or that if some are flushed down the sink anyway. If this does occur, it has never affected the helophyte filter (Hooijer, 2010a).

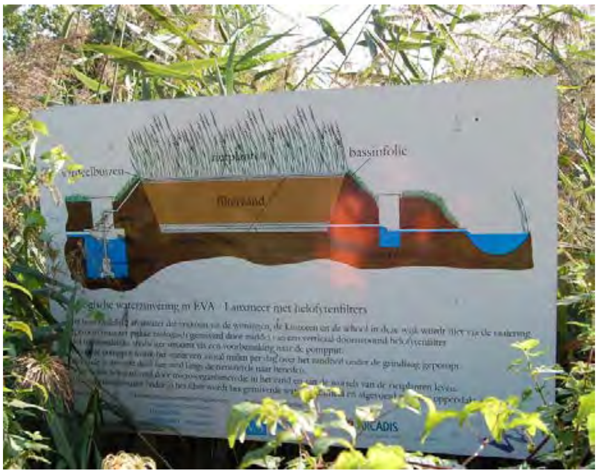


Figure 19. Information sign about the helophyte filters located at the *Station* helophyte filter, Lanxmeer, Culemborg

As the helophyte filters provide shelter to birds and add green to the neighbourhood and fulfil some of the initial objectives of the neighbourhood they are appreciated by the inhabitants. The helophyte filters are perceived as part of the neighbourhood and as something that should be taken care of. Overall, the inhabitants of the neighbourhood keep an eye out for the helophyte filter and will report anything that seems strange to the work group Terra Bella or Mr Hooijer (Hooijer, 2010a; Swinkels and Boland, 2010; Vlietstra, 2010).

- Chlorine
- Bleach
- Medication
- Chemicals (e.g. photo-development, paints)
- Small Chemical Waste (e.g. batteries)

The municipality is positive about the helophyte filters although the amount of maintenance that they require was not anticipated. The large amount of weeding that needs to be done every year was not foreseen, but the overall mind-set of the municipality is that they have constructed the helophyte filters and will also maintain them properly. The positive influence on the environmental conditions and the groups from all over the world that visit the neighbourhood several times per week are also appreciated by the municipality (Hooijer, 2010a; Swinkels and Boland, 2010).

The only critique that the inhabitants, or members of Terra Bella, have about the helophyte filters is that they do not have any insight into how much they cost to maintain and how well they treat the grey wastewater (Noorduyn and Wals, 2003; Swinkels and Boland, 2010). Although they do not need this knowledge for their activities, they instead interested in the helophyte filters and hence keen to be involved. The reason that they have not received this information from the municipality or Water Board Rivierenland is not known to them.

9.8.2. Future

Everything is, and has been, functioning as it should and no problems are foreseen as of yet. The only large unknown is how long it will take before the helophyte filter will need to be rehabilitated.
The municipality will continue to operate and maintain the helophyte filters as they are doing now. As these activities (cleaning sewers, mowing reeds, clearing weeds) are similar to those needed in other locations they are comfortable with this.

Although the *School* and *Unie* helophyte filters are still being used for 50% of their designed capacity construction in Lanxmeer is continuing. Hence they will both be fully used in the near future. It is still unknown if the *Unie* helophyte filter will be able to treat all wastewater coming from the new neighbourhood where houses instead of offices will be constructed, but this is thought not to be an issue by most people (Hooijer, 2010a).

9.8.3. Recommendations

The municipality and inhabitants involved in the management of the neighbourhood would recommend the use of a similar helophyte filter for grey wastewater treatment (Hooijer, 2010a; Swinkels and Boland, 2010; Vlietstra, 2010).

The main recommendation is concerning the environment in which the helophyte filter is located. When designing the surrounding areas it should be kept in mind that maintenance procedures, such as mowing the macrophytes as well as the vegetation surrounding the helophyte filter can be done easily. This could prevent or minimise the growth of weeds in the helophyte filter, as is now the case in the *Station* helophyte filter (Hooijer, 2010a).

Another recommendation is that the current way that the influent is distributed on the helophyte filter could be reconsidered. In all helophyte filters more influent is discharged at the beginning of the distribution pipes than at the end. For instance, holes in the pipes that spread the influent over the reed bed could increase towards the end of the pipes (Santen, 2010). This, however, is doubted by Hooijer, 2010a).

In hindsight it is not the design or construction that was difficult. Instead, it was thought that the maintenance would be easier than that it eventually turned out to be. Although it is still relatively easy, this should not be underestimated. The problems with the weeds are the reason that more hours were needed than originally anticipated (Hooijer, 2010a).

Part D. Analysis, Conclusions, Reflection and Recommendations

10. Analysis

10.1. Grey Wastewater

The literature study conducted on grey wastewater characteristics shows that there is a variance in grey wastewater production and its composition. This is shown in Figure 20, where the ranges of the different pollutants and different cases found in Table 7, Table 8 and Table 9 are shown. Not only is this variance present between different countries, but cases such as Sneek show that the measured characteristics can differ between sampling periods as well. This variance can be explained by the multiple sources that produce grey wastewater, the composition of the soaps and detergents used, the characteristics of the (potable) water supplied and the amount of (potable) water used for the household activities. As these differ per user, time and location grey wastewater characterisation is not straightforward but complex.

Although there is a (large) variance in grey wastewater characteristics, the literature study also revealed that the pollutants all occur within a certain specific concentration range (see Figure 20 as well). These ranges can be quite large, but when the pollutant concentrations are converted to pollutant loads the specific ranges become smaller. This indicates that, although the products used in the household and the different activities cannot be neglected, the amount of water consumed has an influential role in how the grey wastewater is composed. This is seen clearly in cases from Jordan, where the very little wastewater produced was very concentrated. The pollutant loads, however, were similar to the other cases. On the other hand, wastewater that mainly sourced from laundry activities in Israel had similar concentrations to the other cases, but due to the large amount of wastewater produced it had very high pollutant loads.

The composition of the grey wastewater sampled in Lanxmeer was quite consistent, which was not expected as the literature review showed that the composition of grey wastewater varies. Although there were differences between samples collected at the three sampling points, these differences were quite constant. This consistency can be ascribed to the mixing of the grey wastewater in the grey wastewater sewage system and pumping tanks as well as the use of composite samples. The grey wastewater characteristics found in literature show more variance as they not only come from different locations, but also different time periods and different sample types (i.e. grab samples). Hence it would be interesting to see what the characteristics of the grey wastewater in Lanxmeer are in other seasons and how these relate to the characteristics found in this thesis.
The grey wastewater characteristics of the three locations measured in Lanxmeer are presented in Figure 20 as well. They are presented under the category 'Lanxmeer' in one range to compare the general ranges measured in the whole neighbourhood with those found earlier in literature. More in-depth information on the grey wastewater characteristics of the three different locations can be found in section 9.7 and Table 34, Table 36 and Table 38 in Appendices 8 to 10.

BOD_5 and COD concentrations in the grey wastewater sampled at the three helophyte filters in Lanxmeer were quite similar. This was not expected because the grey wastewater at *Station* originates mainly in households, whereas at *School* a large part comes from the secondary school and at *Unie* a school building and some offices are the main sources. At the latter two lower BOD_5 and COD concentrations than at *Station* were expected. This, however, was not the case. One explanation is that the schools and offices produce a relative high amount of biodegradable material. This can be in the kitchens or cafeterias. At *Unie* the higher P-total concentrations indicate that a lot of dishwashing detergents are used, thereby putting more suspicion on the kitchen wastewater. At *School* the showers can also contribute to the biodegradable matter although this is estimated to be very little because students do not use the showers often. Another possibility is that the grey wastewater from households in Lanxmeer contains less biodegradable matter than other (Dutch) cases due to a more ecological mind-set of the inhabitants, although this is not verified. One person spoken to while conducting the filedwork mentioned that at least one office uses conventional cleaning products, including chlorine and bleach, which are all flushed down the sinks.

The BOD_5 and COD concentrations in the grey wastewater in Lanxmeer relatively low, when compared to the other literature cases (Figure 20). One possible explanation is the point of sampling; biodegradation can take place in the grey wastewater sewage systems and pumping tanks. This biodegradation can be considerable as Bleuzé (1995) showed in his design for Polderdrift (Table 17). Hence the grey wastewater characteristics measured in Lanxmeer are not the characteristics of the grey wastewater as it is produced at the source, but rather as grey wastewater that is treated by the helophyte filter (influent). Although the concentrations measured in Lanxmeer will give a wrong impression if they are interpreted as grey wastewater characteristics at the source, they are correct concentrations that should be used when comparing characteristics of grey wastewater before it is treated (influent). This would also explain why the BOD_5 and COD concentrations used by Tauw, and those provided by STOWA, for designing grey wastewater treatment technologies are higher than those actually measured; these concentrations do not take the biodegradation that takes place in the sewage systems into account.

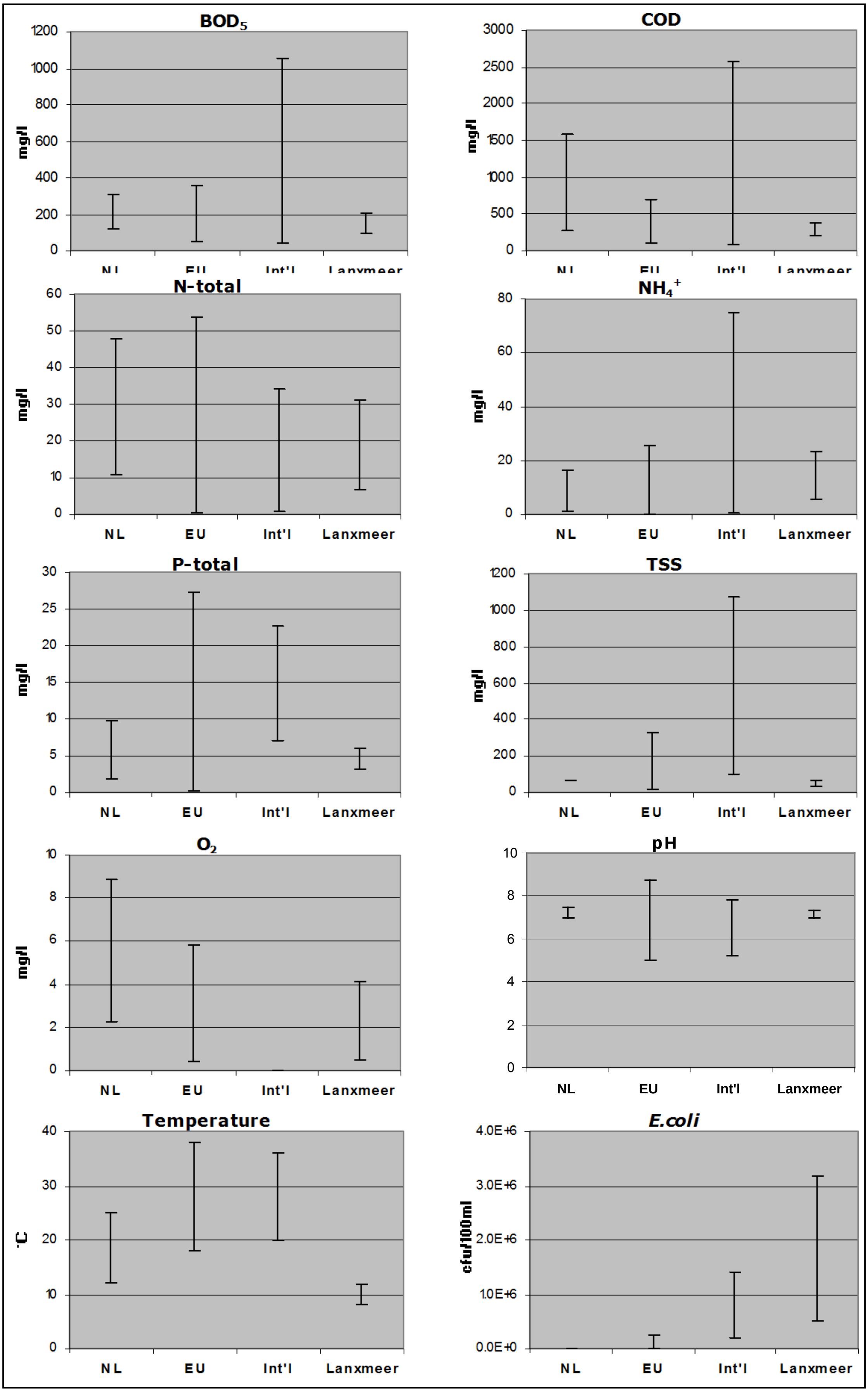


Figure 20. Comparison of grey wastewater characteristics found in literature (Table 7, Table 8 and Table 9) and in Lanxmeer, given in the ranges in which they occur

Another possible explanation is that the grey wastewater in Lanxmeer does not contain any kitchen wastewater, as was noted by SenterNovem (2008). Although this was not mentioned in the different interviews or literature studies conducted during this research it is striking that the concentrations measured during the fieldwork are similar to those previously measured in Lanxmeer by Vitens nv. Note that if the BOD_5 and COD concentrations measured previously in Lanxmeer by Vitens nv would be left out of Table 7 and Figure 20 the smallest concentrations of the ranges shown in Figure 20 will be higher than those measured in Lanxmeer during the fieldwork conducted for this research. Hence although it seems that the BOD_5 and COD concentrations measured during this fieldwork seem to be fitting well within the ranges found in Dutch literature, this is only because concentrations found previously in Lanxmeer are also included in Table 7 and hence in Figure 20.

The N-total, P-total and TSS concentrations measured in the grey wastewater in Lanxmeer are all similar to those found in Dutch and European literature. P-total and TSS concentrations were lower than those recorded in international literature, which can be explained by Dutch and European legislation prohibiting the use of P in laundry detergents and the different household activities. Activities such as washing nappies in the sink and using very little water result in high TSS concentrations, as was the case in Jordan. The grey wastewater at *School* has high N-total concentrations, which probably originate in a faulty connection between the black and grey wastewater sewage systems. This is thought as the N is present in the NH_4^+ form, which originates in urine. If the data from *School* is left out of the graph in Figure 20 the range depicting N-total concentrations for Lanxmeer would be much smaller due to the lower maximum values.
Dutch legislation does not allow P to be used in laundry detergents, but there is no legislation concerning the use of P in dishwashing detergents. This could result in a future increase of P in Dutch grey wastewater the use of as dishwashers is increasing.

Dissolved oxygen concentrations are similar to those found in Dutch and European literature, although they are on the low end of the ranges mentioned. This could be related to the biodegradation that takes place, but it is not clear why this would not be happening at the cases mentioned in literature. The pH of the grey wastewater sampled in Lanxmeer is well within the ranges mentioned in literature. This was expected as there are not a lot of household activities or products that have a large influence on the pH. The grey wastewater temperatures measured during the fieldwork are lower than those found in literature. This, however, can be explained as the samples were collected in the winter when outside temperatures were around freezing point. It is expected that these will be higher when the sampling is done in the summer.

Interestingly, the grey wastewater sampled at all three locations in Lanxmeer had high *E.coli* concentrations. These were on the high end of the ranges found in the literature study, but still in the lower half of the ranges found in domestic wastewater (see section 6.2.5). As only one of the three locations had high NH_4^+ concentrations in the grey wastewater (but similar *E.coli* concentrations as the other two cases) faulty connections between the black and grey wastewater sewage systems at *Station* and *Unie* seem unlikely. However, given past experiences at one of the school buildings this is not impossible and perhaps does occur at small scale. As the temperatures of the grey wastewater measured are favourable for the survival of *E.coli*, another possibility could be that the grey wastewater coming from the sources contains less *E.coli* than was measured, but that the *E.coli* accumulate in the grey wastewater sewage system and pumping tanks. Nevertheless, the measured *E.coli* concentrations were consistent throughout the sampling period and cases, meaning that these concentrations measured are ones that the grey wastewater treatment technology should be able to cope with.

Overall, the concentrations of certain pollutants in the grey wastewater in Lanxmeer are similar to those found in the literature study. Although the BOD_5 and COD concentrations are lower, this could be attributed to the biodegradation that occurs in the grey wastewater sewage pipes and/or inhabitant behaviour. As the grey wastewater characteristics are influenced by the products and amount of water that are used in the household, school or office, the concentrations measured in the samples collected during the fieldwork can differ from similar samples collected at the same location in another time period (e.g. summer).
Nevertheless, the characteristics of the grey wastewater sampled from the three locations in Lanxmeer are a valuable addition to the literature on grey wastewater. Not only do they show that at one location grey wastewater can be of a steady composition during a certain time period, but also that the composition of can differ per sampling location within one neighbourhood. The latter is also shown in the literature studies, where large differences between different sampling periods at a certain case can be seen.

When comparing the characteristics of the grey wastewater sampled with the characteristics of the wastewater that the V-SSF helophyte filter should be able to treat according to the Dutch guidelines (Table 4), one can see that the concentrations mentioned in these guidelines are much higher. Even if these concentrations are halved (as a V-SSF helophyte filter treating grey wastewater is half the size of a V-SSF helophyte filter treating domestic wastewater) the grey wastewater from Lanxmeer is still less polluted that the design criteria state, but not by much. One could state that this is no problem as the designs will be on the safe side by assuming more concentrated grey wastewater, but on the other hand, if the grey wastewater characteristics measured in Lanxmeer are representative for Dutch cases (which we do not know as the grey wastewater characteristics found in literature were either calculated figures (Telkamp, 2010), derived from older cases in STOWA reports or found at other Dutch cases such as Sneek where the grey wastewater volumes are smaller than the Dutch average), it could lead to continuous over designing, which is more expensive.

A point of critique is that the pollutant loads cannot be calculated as the volume of grey wastewater produced per person per day is not known. As the pollutant concentrations are different from figures generally assumed to be the Dutch averages and Lanxmeer is not per se an average Dutch neighbourhood it was decided not to use the known average Dutch grey wastewater volumes produced per day. The known average values of Drielanden or Sneek were not used because of the large differences (100 l/c/d and 60 l/c/d, respectively; see Table 7 as well), which would result in very vague numbers. Hence it is not possible to compare the loads of the grey wastewater from Lanxmeer with loads recorded in literature.

A side note is that although the effluent of the helophyte filters in Drielanden and Lanxmeer is compared to the effluent of the wastewater treatment plant in Culemborg in the next section, the influent of the wastewater treatment plant is not compared to the grey wastewater characteristics found in literature and during the fieldwork (Figure 20). The characteristics of this influent, measured from 3-1-2011 till 30-4-2011 are provided in Table 94 in Appendix 17 but because the influent consists of domestic wastewater, industrial wastewater and surface runoff it is outside of this study to compare them thoroughly.[34]

10.2. Helophyte Filters

The first literature study shows that helophyte filters are complex natural wastewater treatment technologies. Different processes take place throughout the helophyte filter, and each process is responsible for a (small) part of the removal of pollutants. For the removal of certain pollutants, e.g. NH_4^+, specific processes such as ammonification, nitrification and denitrification are required to happen in a certain sequence where each process has its own unique requirements in order to have effect. On the other hand, the removal of P happens via different processes that can take place throughout the whole helophyte filter on different scales and independently of each other. The removal of pathogens from wastewater with a helophyte filter is not as straightforward because the surroundings of a helophyte filter can be favourable or unfavourable for the pathogens depending on the climate and characteristics of the influent. Although processes such as filtration do have a large impact, the actual pathogenic concentrations in the effluent can differ per measurement. Most of the degradation of mainly organic material usually takes place in the top layer of the helophyte filter where most oxygen is available. This can result in less C being left over for denitrification processes that take place in the deeper anaerobic zones, showing that the pollutant removal processes can be interrelated.

10.2.1. Technology

A proper design and well performed operation and maintenance procedures determine how well the wastewater infiltrated into the helophyte filter. This, in turn, determines if noxious odours are produced and how well pollutants are removed. This was demonstrated in Drielanden, where the V-SSF helophyte filter was constructed with too fine filtration sand. The V-SSF helophyte filter in Polderdrift showed that poor pumping regimes can clog the top layer of the helophyte filter, which resulted in puddle formation and noxious odours. On the other hand, if helophyte filters are properly operated and maintained like they are in Lanxmeer the occurrence of issues such as clogging become less likely. It should be noted that the helophyte filters in Lanxmeer also produce noxious odours several times per year but the inhabitants of the neighbourhood generally accept this as part of the technology.

The design and construction of a helophyte filter, as the Polderdrift case showed, should be done with care. Here the suitability of the construction materials used is doubted and since completion the helophyte filter has been modified several times as it did not function properly. These shortcomings in the design and construction, as well as the modifications to the pumping regimes and distribution piping system have resulted in the current need to rehabilitate the whole helophyte filter.

The landscape in which the helophyte filter is constructed should be designed in such a way that the maintenance procedures can be performed easily and efficiently. Although this aspect is not mentioned in the Dutch guidelines, the case studies have shown its significance. The *Station* helophyte filter in

[34] At a first glance it can be seen that the BOD_5 concentrations of the influent at the wastewater treatment plant are comparable to the concentrations found in grey wastewater from Lanxmeer. COD concentrations show more variance and are sometimes a bit, other times a lot, higher than the concentrations found in grey wastewater. N concentrations in the influent of the wastewater treatment plant are also higher. P-total concentrations are a bit higher, but not much, than those found in the grey wastewater and TSS concentrations are much higher.

Lanxmeer and the helophyte filter in Polderdrift were both surrounded by trees or shrubs. This not only resulted in more dead plant material and seeds accumulating in the top gravel layer, but also made the controlling of weeds in and surrounding the helophyte filter more difficult. The surrounding vegetation was difficult to mow or prune thereby creating opportunities for plants to invade the helophyte filter and overgrow the macrophytes. A critical note here is that little research has been done on the influence of the weeds on the performance of a helophyte filter. This influence is not per se negative, although certain plants, such Willows (*Salix* sp.), can damage the helophyte filter (Vymazal and Kröpfelová, 2008). Although most macrophyte species are generally aggressive and do not allow for much weed growth, weeding can be considered necessary as it enhances the aesthetic value of the helophyte filter.
The location of the helophyte filter will also determine which buildings will be most affected by the noxious odours that the helophyte filter can produce (see section 10.2.5). Hence the predominant wind direction should also be incorporated in the overall design of the neighbourhood to minimise odour nuisance.

10.2.2. Actors

All three cases had sustainability and ecological-conscious construction as part of the initial objectives. These were formulated by either the municipality who wanted to do something different or a group of people with ecological ambitions. In all cases the municipality was involved and provided the means to get the project running. As the municipality was involved the legislative procedures could have been completed more smoothly, but they also had more resources such as land and finances. In all cases an enthusiastic person or organisation was present as a driving force.

The design and construction of the helophyte filters was done by an engineering bureau (Grontmij in Drielanden) or helophyte filter construction company (RietLand in Polderdrift and BrinkVos Water in Lanxmeer). In Lanxmeer a local construction company was responsible for constructing the three helophyte filters. In Polderdrift and Lanxmeer it became clear that proper construction is essential for proper functioning. Because the pumps were not properly located in Polderdrift and there are doubts about the quality of the impermeable layer at the bottom of the helophyte filter several modifications and investments in studies on the lack of effluent have been made. This resulted in higher costs. On the other hand, the helophyte filters in Lanxmeer were constructed properly and no adjustments had to be made to the physical systems after they were completed.
It should be noted that the grey wastewater sewage system in Lanxmeer had several wrong connections resulting in the mixing of black wastewater with grey wastewater in at least one location (*Unie*). This is a general risk of installing several piping systems in one building or area (as was also seen in Leidsche Rijn).

The actors responsible for the operation and maintenance are the municipality in Drielanden and Lanxmeer, and the inhabitants and the Housing Corporation (Portaal) in Polderdrift. Although in the latter case there is a maintenance plan this is not adhered to. Instead, maintenance procedures seem to be done ad hoc. Portaal is responsible for the larger procedures such as cleaning the grease traps, but these too seem not to be part of their scheduled maintenance rounds. It is not clear who is responsible for the helophyte filter, resulting in initiatives from inhabitants. Actions such as digging holes in the helophyte filter to investigate the clay layer and removing the distribution piping system from the gravel layer are performed by the inhabitants on their own initiative.
In Drielanden and Lanxmeer the helophyte filters are part of the operation and maintenance routine of the municipality. As a result the maintenance procedures are performed as well as the periodic checks. The inhabitants are not involved in the procedures but instead help with checking the system by notifying the municipality of something is wrong.
The latter construction seems to be working best as the scheduled maintenance procedures are performed on time and a larger organisation with more capacities is responsible for the helophyte filters. Whereas inhabitants of a neighbourhood would like to be involved with the operation and maintenance of the helophyte filter this can result in ad hoc actions that are based on trial and error. These inhabitant organisations often do not have the tools and knowledge to perform the large maintenance procedures, such as mowing and getting rid of the clippings. Furthermore, if problems occur with the helophyte filter or pumps the inhabitant organisation will need to get assistance from the Housing Corporation who might not be up to date on problems of the helophyte filter, its necessity or what actions have been taken in the past. Hence, for a smoother and more efficient conduction of the operation and maintenance procedures a well organised and motivated organisation with the capacity and knowledge to perform these procedures seems to be best.

10.2.3. Operation and Maintenance

Overall, the helophyte filters need relative little maintenance as the cases have shown. However, like prescribed in the Dutch guidelines some maintenance is needed, which is essential for ensuring that the helophyte filter continues to perform well. Not only should the macrophytes be mown to allow for better growth and nutrient removal, but weeds need to be removed and gravel replaced if it clogs. The latter will prevent puddles from forming (and hence noxious odours), whereas it is unknown if the removal of weeds directly influences the treatment capacity of the helophyte filter. By removing the weeds the helophyte filters are also kept neat and tidy, making them more aesthetically pleasing and up keeping the social support for the use of helophyte filters for wastewater treatment.

The distribution pipes need to be checked for blockages as well as loose connections that can result in puddles. As the latter can result in the clogging of the helophyte filter it is an essential aspect. By checking and annually cleaning the grease trap solids are removed that would otherwise flow into the distribution pipes. Here they could clog the perforations or pipes, resulting in malfunctioning.

The operation and maintenance of the pumps is straightforward in each of the cases. Nevertheless, if the pumps do malfunction the wastewater will accumulate in the pumping tank, which will eventually overflow. Although this is of no consequence in the analysed cases as the overflow is connected to the conventional sewage system, the helophyte filter will not be functioning, which is a waste. Hence the pumps, with its timing system and reliable energy source, form a critical part in of the helophyte filter.

10.2.4. Costs and Financing

As both Polderdrift and Lanxmeer have shown, the construction costs of a helophyte filter can be considerable. In all three cases these costs were paid for by a municipality or Housing Corporation with the capacity to pay for the helophyte filter. As each of the three cases was an ecological project fund for the constructing of the helophyte filters were found. However, given the high construction costs per house (€6810.- in Polderdrift and €1600.- in Lanxmeer; or €2840.-/p.e. and €670.-/p.e., respectively[35]) it is not certain if the inhabitants would be able, or want, to pay for the construction themselves.

The costs for operating and maintaining a helophyte filter in Lanxmeer, including the maintenance of the sewage systems needed to collect and transport the different wastewaters, are similar to the fees inhabitants pay to the municipality for using the sewage system (between €230.- and €285.-). The sole operational costs over 2010, consisting of annual checks and the electricity and phone bills, were quite low (€10.- per household), whereas the maintenance costs were higher (€70.-). The main maintenance costs consisted of weeding and renewing the top gravel layer (41 per cent). For comparison, the maintenance of the pumps was responsible for 26 per cent of the total maintenance costs. The remaining 11 per cent and 22 per cent were used for mowing and discarding the clippings, respectively. The largest expense of the helophyte filter, during 2010 were the renewal costs (€80.-), of which 71 per cent was spent on the renewal of the helophyte filter, 24 per cent for the renewal of the pumps and the remaining 5 per cent for the renewal of the pumping tanks. The different life spans (25, 15 and 30 years, respectively) were taken into account, but not inflation rates. Although not part of the actual helophyte filter, the costs for cleaning the four different sewage systems in the neighbourhood were given as well to see whether the whole wastewater system would be more expensive than the fee that the inhabitants pay for using the sewage systems. As no concrete data were available, annual indication costs were determined using Dutch indicators. As a result, the annual maintenance costs of all four sewage systems located in Lanxmeer ranged from €70.- to €125.- in 2010. This figure can be divided by four if the grey wastewater system only is taken into account. This, however, is not done as the different sewage systems are considered essential for the overall wastewater treatment of the neighbourhood. Hence if a grey wastewater sewage system is constructed, separate sewage systems for the black wastewater, surface runoff and rainwater collected from the roofs[36] are also needed. Furthermore, the inhabitants pay one fee for using all four sewage systems.

In all cases a large organisation was responsible for the financing, although in Polderdrift different companies also used the helophyte filter for promotional purposes. The construction costs were considerable and needed within a short time span, making it difficult for small groups or private initiatives to realise a helophyte filter on neighbourhood scale. This proved less difficult for the municipality or Housing Corporation who incorporated the costs into the construction costs for the whole neighbourhood.
The above analysis of the annual costs shows that the inhabitants of Lanxmeer were able to finance the operation, maintenance and renewal costs as well as the maintenance costs for the sewage systems. It thus seems that once constructed the running costs can be financed by the users themselves. This was also the case for the inhabitants of Polderdrift, although the costs made by the Housing Corporation were sporadic and not clear. Hence they were not included in the analysis above. Also, the inhabitants of

[35] Note that the large difference in costs is due to the different aspects included (In Polderdrift the whole grey wastewater treatment system, including the sewage pipes, are included whereas the construction costs in Lanxmeer only consist of the helophyte filters and pumps); the different timer periods in which the helophyte filters were constructed as materials or technologies could have become cheaper and the difference in scale (Lanxmeer currently is has more than 60 times the houses of Polderdrift).

[36] In certain cases the surface runoff and rainwater collected from roofs are collected in one sewage system instead of two individual sewage systems.

Polderdrift have not saved any money for renewing the helophyte filter, meaning that they, with the Housing Corporation, are now looking for other ways to finance the renewal of the helophyte filter.

Interestingly, most of the maintenance costs were spent on weeding and renewing the top gravel layer. If less weeding would be needed by using a more aggressive macrophyte that has less tolerance to other invasive species money could be saved. In addition, the discarding of the clippings also costs a substantial amount of the maintenance budget. If ways could be found to reuse the clippings money could be saved as well. In the most ideal situation, where no to little weeding is needed and the profit of using the clippings is equal to the costs of discarding it, about 60 per cent of the maintenance costs (€42.- per household per year) can be saved. Furthermore, if the helophyte filter is constructed in such a way that the water flows by gravity instead of pumps, another 26 per cent can be saved on maintenance costs as well as 24 per cent of the construction (and renewal) costs of the pumps. In reality this will be less as flow-regulating devices are still needed, but this will not be much as some of them are used now as well (e.g. float valves).

10.2.5. Functioning

All helophyte filters produce noxious odours several days per year when it is warm. However, in none of the cases formal complaints about this have been made. Instead, the odours seem to be accepted as part of the technology and are sometimes compared to the stench coming from farmers applying manure on their fields. Although concerns for noxious odours were common during the initial planning phases, this proved to be acceptable in all cases once the helophyte filters were functioning. Most complaints related to noxious odours came from inhabitants living in Polderdrift whose houses were located down-wind of the helophyte filter. In Drielanden the V-SSF helophyte filter initially implemented as part of the grey wastewater treatment system was demolished after it produced too much noxious odours, despite its good removal efficiencies (see next section as well). This indicates that noxious odour nuisance is acceptable, but it should be taken seriously as there are boundaries to what inhabitants will accept.

None of the helophyte filters have been considered as a risk or increase in threat to the public health. An increase in pests has not been noticed by the people living around the helophyte filter, and neither have any cases of malaria been linked to the helophyte filters. Although the helophyte filters treat grey wastewater in public areas no cases of illness related to these helophyte filters have been found, despite people sometimes entering the helophyte filters. In the case of Drielanden, no one has drowned in the FWS helophyte filters. These are considered less of a threat than the canals that run through the neighbourhood.

All three cases experienced operational errors. The majority of these occurred during the start-up phases when the pumping regimes had to be figured out. The older cases (Drielanden and Polderdrift) had more issues, related to the design, which had to be solved as well. The location of the pumps in Polderdrift had to be changed and the V-SSF helophyte filter in Drielanden had to be removed to ensure better functioning. In the latter case the overall design was changed (construction of a cascade and the mixture of effluent of the first FWS helophyte filter with influent) to improve the pollutant removal efficiencies.
In Polderdrift there were issues with the grey wastewater sewage system as well. There were several blockages each year, resulting in minor maintenance works. This, however, was later solved by using less 90 degree bends where solids can accumulate. Blockages in the grey wastewater system do not occur in Drielanden or Lanxmeer and it seems that this was part of the start-up problems associated with the first implementation of a certain technology.

The influence of the helophyte filters on the environment has been positive in all three cases. The surface water quality has been improved in Drielanden as it flows through the second FWS helophyte filter as well. Although this is not the case in Polderdrift and Lanxmeer, where the surface water is not treated by the V-SSF helophyte filters, the macrophytes add to the aesthetic value of the neighbourhood and result in an increase of the local biodiversity.

10.2.6. Performance

There is little data available on the performance of helophyte filters that are in use for several years. If measurements were done, these were usually in the form of grab samples of the effluent only. This was the case in Drielanden, where Royal Haskoning conducted a small study in 2008, and Polderdrift, where the effluent was analysed for *Legionella pneumophila* by C-mark in 2003. The Water Board Rivierenland takes annual grab samples of the effluent in Lanxmeer to check permit compliance. These grab samples result in scattered information on effluent quality. These studies cannot be used to determine the removal efficiencies of the different helophyte filters as the influent is not analysed.

Figure 21 shows an overview of the effluent characteristics of different helophyte filters and a wastewater treatment plant. It should be noted that the ranges in which the effluent concentrations are shown are

not weighed. This means that the ranges show the maximum and minimum concentrations of each pollutant. These maximum and minimum concentrations could be outliers from the mean.
The data behind Figure 21 are found in the following Tables: V-SSF helophyte filter (Table 13 and Table 14) and the first (Table 11) and second (Table 12) FWS helophyte filters are described in the Drielanden case (Chapter 7). The study by Vitens nv in Lanxmeer (Table 23) and the results of the samples collected during the fieldwork (Table 25, Table 27 and Table 28; *Station*, *School* and *Unie*, respectively) are also described in Chapter 9. The effluent of the wastewater treatment plant in Culemborg comes from Table 95 in Appendix 17. Although the latter does not treat grey wastewater but a mixture of domestic and industrial wastewater with surface runoff it is included to compare the effluent of the helophyte filters in Lanxmeer with the effluent of a wastewater treatment plant. As the standard sampling procedure at a Dutch wastewater treatment plant is by a 24 hour composite sample and the samples taken in Lanxmeer were also composite samples[37] the results are comparable. In this case the effluent of the wastewater treatment plant can serve as a benchmark.

V-SSF Helophyte Filter in Drielanden

The influent and effluent of the V-SSF helophyte filter in Drielanden has been sampled twice by Dijk (2000). This was done on 8-11-1996 and 8-12-1996. Soon after this the V-SSF helophyte filter was demolished due to clogging, flooding and noxious odour production. The influent characteristics are included in Table 7 under the column 'Groningen' (Dijk, 2000) and in Figure 20 under 'NL'. Figure 21 compares the effluent of the V-SSF helophyte filter with the FWS helophyte filters in Drielanden as well as the helophyte filters in Lanxmeer and the effluent of the wastewater treatment plant in Culemborg.

The BOD_5 and COD concentrations are both higher than those recorded in the effluent of Lanxmeer, but well within the ranges in which the BOD_5 and COD concentrations occur in the effluent of the two FWS helophyte filters. N-total could not be analysed as it was not included in the analyses of Dijk (2000) but the NH_4^+ concentrations found in the effluent of the V-SSF helophyte filter in Drielanden were lower than the other concentrations measured. The same goes for the P-total concentrations. The TSS concentrations are on the high side of those measured at the wastewater treatment plant, but on the low end of the range in which the TSS concentrations are found in the effluent of the FWS helophyte filters in Drielanden and V-SSF helophyte filters in Lanxmeer. The pH of the effluent was a lot lower than the other cases, but not much. Unfortunately, dissolved oxygen, temperature and *E.coli* were not analysed by Dijk (2000).

As the hydraulic retention time (HRT) of the V-SSF helophyte filter in Drielanden is not known the influent and effluent measurements taken on the same day were used to calculate the removal efficiencies. With the general HRT of 24 hours that is maintained for V-SSF helophyte filters this is not entirely correct, but as the influent is mixed in the collection tank, the wastewater is mixed in the helophyte filter and the influent and effluent characteristics measured during the fieldwork in Lanxmeer were relatively stable, these calculations can be used as an indication for that time period.
The calculated average BOD_5 removal efficiency of the V-SSF helophyte filter in Drielanden was 98.6 per cent; for COD this was 87.4 per cent. As N-total was not analysed, the TKN concentrations were used. The TKN removal efficiency was 92.5 per cent. For P-total this was 94.2 per cent and TSS 67.5 per cent. The effluent had a pH of around 6.
As noted earlier, this helophyte filter was demolished less than half a year after it was taken into use. Hence these removal efficiencies cannot be attributed to a helophyte filter that has been in use for several years, but they do provide some insight into the performance of a V-SSF helophyte filter that is being used in the winter and which is flooding. The BOD_5, TKN, and P-total removal efficiencies during these two months were quite good. The COD removal efficiency was a bit lower but the concentrations in the effluent were still satisfactory (34-38 mg/l). The lowest removal efficiency recorded was for TSS concentrations. This was expected as TSS removal is not as good in a V-SSF helophyte filter as it is in an H-SSF helophyte filter. Nevertheless, the effluent showed low TSS concentrations (7.8 mg/l) which are well within the concentrations set for an IBA Class IIIB by Dutch legislation (30 mg/l). Overall, based on the effluent characteristics and the removal efficiencies of the V-SSF helophyte filter during the winter period one can wonder if the demolition of this helophyte filter made sense. However, the argument that the odours produced due to flooding were too noxious for the inhabitants was stronger than its good removal efficiencies.

FWS Helophyte Filters in Drielanden

The effluent of the two FWS helophyte filters in Drielanden are both shown in Figure 21 to see what the influence of the two FWS helophyte filters is on the quality of the effluent. As the effluent is transported from the first to the second FWS helophyte filter by a pipe the effluent of the second helophyte filter should comply with the permit requirements. BOD_5, NH_4^+, P-total, TSS and pH are all reduced

[37] Although these were 11-hour composite samples most grey wastewater was thought to be produced in this time span. As a result the aliquots were collected as the majority of the grey wastewater was produced, making the results comparable. For more background see section 4.3.3.

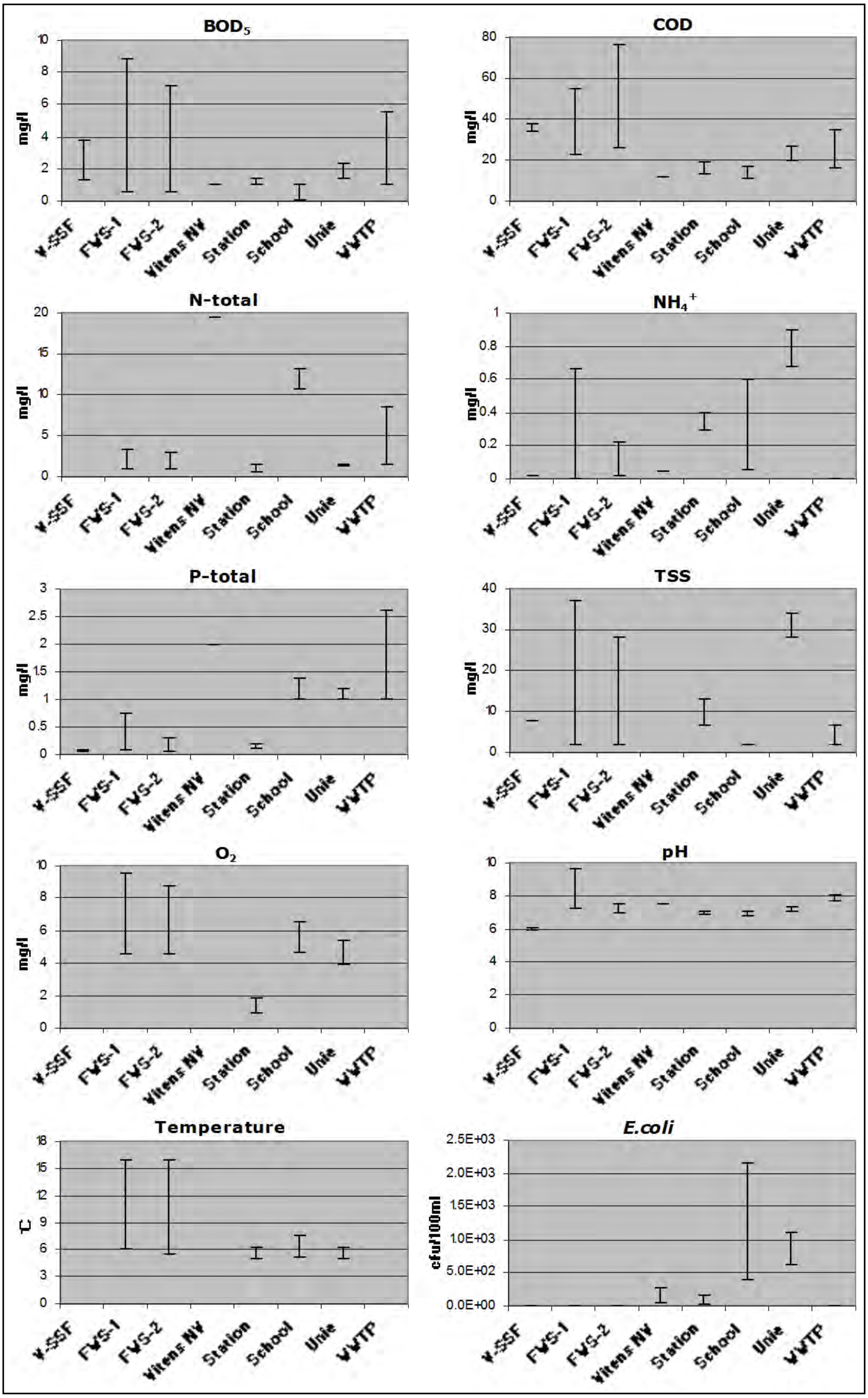


Figure 21. Comparison of effluent of different helophyte filters in Drielanden (V-SSF, FWS-1 and FWS-2), Lanxmeer (Vitens nv, Station, School and Unie) and the wastewater treatment plant in Culemborg (WWTP), given in the ranges in which they occur

significantly in the second FWS helophyte filter. The ranges for N-total and dissolved oxygen in effluent from the second FWS helophyte filter are a bit lower than those in the effluent of the first FWS helophyte filter but this is not a lot. Interestingly, the COD concentrations seem to increase in the second FWS helophyte filter. A comparison between Table 11 and Table 12 shows that this is because there are two high COD concentrations measured in the effluent of the second FWS helophyte filter; the majority of the COD concentrations measured in the effluent of the second FWS helophyte filter are similar or lower than those in the effluent of the first FWS helophyte filter. The reason for the two peaks is not known but could be related to a disturbance of the FWS helophyte filter such as stirring, which can result in a sudden release of pollutants that have accumulated in the sediment. The temperatures of the effluent are very similar. This is logical as both FWS helophyte filters are constructed in the open air and hence the water temperatures are influenced by the climate. Interestingly, the majority of the ranges of the pollutants found in the effluent of the second FWS helophyte filter are all smaller than the ranges found in the effluent of the first FWS helophyte filter. This is not the case for the COD concentrations, which is because of the high peak that were measured, al explained earlier, and the temperatures of the effluent, where there was one lower measurement. Nevertheless, the data show that the second FWS helophyte filter shows a more consistent effluent composition than the effluent of the first FWS helophyte filter, and that in most cases more pollutants were removed as well.

In relation to the other helophyte filters, Figure 21 shows that the concentrations of most of the pollutants in the effluent are ranges in which the pollutants are found are larger than the other helophyte filters. Only the ranges for N-total, NH_4^+, P-total and dissolved oxygen concentrations in the effluent of the second helophyte filter are similar or smaller than those found at some of the other helophyte filters. The maximum values in the ranges of BOD_5, COD and TSS concentrations are all higher than the other helophyte filters. As filtration processes hardly occur in a FWS helophyte filter and external inputs such as dead plant material and (water) bird faeces can accumulate in the water close to the outflow point these higher concentrations are explainable.
The N-total, NH_4^+ and dissolved oxygen concentrations are all similar to those found in the effluent of the other helophyte filters. The same goes for the pH. The main difference is that the ranges of the FWS helophyte filter are generally larger than those of the effluent of the other helophyte filters, which is why the results are similar. However, the V-SSF helophyte filters generally show smaller ranges that are not always similar, meaning that if an individual V-SSF helophyte filter is compared with the second FWS helophyte filter the V-SSF helophyte filter will, in general, show lower concentrations in the effluent with less variance.
P-total concentrations in the effluent of the second FWS helophyte filter are similar to those measured at *School* in Lanxmeer but much lower than the other effluents, including that of the wastewater treatment plant. This can be related to the type of macrophytes used, which could have a better P uptake. Another possibility is the binding of P to organic matter or sedimentation that takes place in the FWS helophyte filter.
The temperature ranges are larger for the FWS helophyte filter, but this is logical as the measurements span a larger time period than those taken in Lanxmeer. This larger time span results in warmer water temperatures, present in the summer, are also included in the range. Unfortunately, *E.coli* was not analysed for in the study by Dijk (2000) and hence no comparisons can be made.

The HRT of the first FWS helophyte filter is 18 days and 2 days for the second FWS helophyte filter. As the influent and effluent data were analysed monthly, the average removal efficiencies could not be calculated because the analysed influent sample does not correspond with the analysed effluent sample. Furthermore, due to the large HRT's there is a lot of mixing of water in the FWS helophyte filters making it difficult to follow a batch of grey wastewater through the helophyte filters without a tracer.

V-SSF Helophyte Filters in Lanxmeer

The effluent of the three V-SSF helophyte filters in Lanxmeer differs per location. Even though the influent and helophyte filters are comparable the differences between the three locations in Lanxmeer (*Station*, *School* and *Unie*) in Figure 21 can be seen clearly. The ranges of the BOD_5 and COD concentrations are similar although a consistent difference between *Unie* and the other two can be seen; its range is a bit higher. The concentrations are lowest in effluent from *School*. N-total concentrations are higher in the effluent of the *School* helophyte filter than in the effluent of *Station* and *Unie*. These high N-total concentrations were related to the high NO_3^-concentrations found in the effluent, as explained in section 9.7. The NH_4^+ concentrations showed a relative large amount of variance in the effluent of *School*, whereas at *Station* the variance was a relatively small. The effluent of *Unie* showed the highest NH_4^+ concentrations. P-total concentrations are lowest in the effluent from *Station* and highest at *School*. The effluent from the helophyte filter at *Unie* showed the highest TSS concentrations, whereas the helophyte filter at *School* produced effluent with lowest TSS concentrations. The dissolved oxygen concentrations were consistently lower in the effluent from the *Station* helophyte filter. They were comparable in the effluent from the other two helophyte filters. As was expected, the pH of the effluent was comparable for all three helophyte filters due to the sources of the influent and buffering of the helophyte filters. The same goes for the temperatures of the effluent, which were similar during the field work. The lowest

E.coli concentrations were measured in the effluent from *Station* and highest in the effluent from *School.* The latter shows quite a large range, which can be explained by two composite samples with high *E.coli* concentrations; the other composite samples had much lower concentrations (around 500 cfu/100 ml). This shows that the *E.coli* concentrations were in general higher in effluent from the *Unie* helophyte filter. The difference in *E.coli* concentrations between location but also sample can be substantial, as Figure 21 shows. This also indicates the importance of using multiple composite samples when analysing (grey) wastewater to ensure that the role of outliers is minimised.

In relation to the helophyte filters from Drielanden the effluent of the three helophyte filters analysed during the fieldwork has low BOD_5 and COD concentrations. This is also confirmed by the study previously done in Lanxmeer by Vitens nv The ranges of these BOD_5 and COD concentrations are also smaller than the range seen at the wastewater treatment plant in Culemborg, where the maximum BOD_5 and COD concentrations measured are higher than those recorded in Lanxmeer. The same goes for the N-total concentrations of the *Station* and *Unie* helophyte filters compared to the effluent of the wastewater treatment plant. The effluent of the *School* helophyte filter showed higher N-total concentrations present in the form of NO_3^-. The N-total concentrations measured in the effluent of the FWS helophyte filters was comparable to that of the *Station* and *Unie* helophyte filters. The effluent from the *Unie* helophyte filter had the highest NH_4^+ concentration, whereas the effluent from the FWS helophyte filters and *School* helophyte filter had the most variance for this pollutant. The P-total concentrations in the effluent in Lanxmeer (except at *Station*) were a bit higher than those recorded in Drielanden but still lower than those recorded in the effluent of the wastewater treatment plant in Culemborg. The helophyte filter at *Unie* consistently produced effluent with relative high TSS concentrations. The TSS concentrations in the effluent of the *Station* helophyte filters in Lanxmeer was comparable to the TSS concentrations found in the effluent of the V-SSF helophyte filter in Drielanden, much lower than the concentrations in the effluent of the FWS helophyte filters but higher than those found at the wastewater treatment plant. The *School* helophyte filter had the lowest TSS concentrations; these were on the low side of those measured in the effluent of the wastewater treatment plant. Again, most dissolved oxygen, pH and temperature levels were comparable between the different helophyte filters from Drielanden and Lanxmeer as well as the effluent from the wastewater treatment plant (only pH; the other parameters were not measured there). The only exception was the effluent from the *Station* helophyte filter, which showed low dissolved oxygen concentrations. Unfortunately, there was no data on the *E.coli* concentrations in the effluent of the wastewater treatment plant and the helophyte filters from Drielanden. Hence these could not be compared. However, the *E.coli* concentrations previously measured in Lanxmeer by Vitens nv (SenterNovem, 2008) are comparable to those measured at the *Station* helophyte filter, indicating that the helophyte filter analysed by Vitens nv could be the *Station* helophyte filter. Furthermore, as this study was conducted in September, it could be an indication that *E.coli* concentrations are fairly constant, with a certain degree of variance, year-round. However, there is not enough data available to confirm this.

The intensive two weeks of fieldwork conducted in Lanxmeer have resulted in characteristics of the influent and effluent of three helophyte filters. These in turn have been used to calculate five removal efficiencies per helophyte filter, meaning that in total 15 removal efficiencies for the different pollutants have been calculated. For BOD_5 these ranged from 97.7 to 99.9 per cent, which is very good. The removal of COD was a bit less, but still quite high; 89.1 to 96.7 per cent. The N-total removal efficiencies of two V-SSF helophyte filters (*Station* and *Unie*) ranged from 80.2 to 95.0 per cent. For the *School* helophyte filter this was 42.8 to 57.4 per cent, which is much lower. This can be attributed to the higher concentrations of NO_3^- in the effluent. The removal efficiencies of NH_4^+ at the *School* helophyte filter ranged from 96.2 to 99.7 per cent, which is good. The removal efficiencies of P-total had a much larger range; 67.5 to 97.5 per cent. The ranges per helophyte filter were much smaller, with *Station* recording 95.9-97.5 percent, *School* 69.4 to 72.6 per cent and *Unie* 77.4 to 83.6 per cent. The same goes for the removal of TSS, which ranged from 19.4 to 96.6 per cent (*Station* 75.0 to 87.3 per cent; *School* 96.2 to 96.7 per cent; *Unie* 19.4 to 54.1 per cent). The dissolved oxygen concentrations at *Station* increased twice by only 0.2 mg/l and decreased three times by 0.6 mg/l. It increased at *School* by 4.6 mg/l on average and at *Unie* by 1.1 mg/l, on average. The pH of all effluents was around 7 and the temperatures of the grey wastewater decreased in the helophyte filter from 9-11 ºC to 5-7 ºC. The ranges in these temperatures can be explained by the climate as well as the distance that the grey wastewater had to travel to the helophyte filter as it cools down along the way. Interestingly, the variance in the removal of *E.coli* was log 2.5 to 5.2. Again, this range was not this large for all helophyte filters, but the *Station* had consistently better *E.coli* reduction rates than the other two helophyte filters. The cause for this is unknown, but it should be noted that these reduction rates are higher than those mentioned by EPA (1993), which states that a SSF helophyte filter is in general capable of a log reduction of 1 to 2.

Wastewater Treatment Plant in Culemborg

Lastly, the effluent of the helophyte filters is compared with the effluent from the wastewater treatment plant in Culemborg. BOD_5 and COD concentrations were similar to those found in Lanxmeer during the fieldwork, although there is more variance in the data from the wastewater treatment plant. This could

be explained by the dataset, which includes effluent characteristics from January till May 2011. In these measurements there is one high BOD_5 concentration of 5.7 mg/l; the others are all around 2-3 mg/l (See Table 95 in Appendix 17 as well). The same sample also showed higher COD concentrations (35 mg/l). The other COD concentrations measured in the effluent of the wastewater treatment plant ranged from 20-30 mg/l. In both cases the effluent of the *Station* and *School* helophyte filter showed lower concentrations. The effluent of the *Unie* helophyte filter was similar to that of the wastewater treatment plant. The BOD_5 concentrations are similar to those measured in Drielanden, although the latter showed more variance. COD concentrations were a bit higher in the effluent from Drielanden than those in the effluent from the wastewater treatment plant.
The N-total concentrations in the effluent of the wastewater treatment plant have a higher variance than those in the other effluents. As the TKN concentrations in the effluent of the wastewater treatment plant were around 2 mg/l (See Table 95 in Appendix 17), the higher N-total concentrations are because of fluctuating NO_3^-, concentrations in the effluent. These TKN concentrations are higher than those found in the effluent of all types of helophyte filter. The effluent of the *School* helophyte filter and those found in the study by Vitens nv do show higher N-total concentrations, but these are both in the form of NO_3^-.
P-total concentrations in the effluent of the wastewater treatment plant also show a lot of variance, with the majority of the recorded concentrations being around 2 mg/l. This is higher than any of the other P-total concentrations found in the effluent of the different helophyte filters. It should be noted that in general the P-total concentrations were a bit higher in the influent of the wastewater treatment plant than the influent of the helophyte filters in Lanxmeer (6 mg/l vs. 3-5 mg/l, respectively) (See Table 94 in Appendix 17 as well).
TSS concentrations in the effluent of the wastewater treatment plant were lower than most of those measured in the effluent of the helophyte filters. Only the *Station* helophyte filter had lower TSS concentrations, although the effluent of the FWS helophyte filters showed low concentrations as well. Nevertheless, the effluent of the FWS helophyte filters also had much higher TSS concentrations, as the ranges in Figure 21 show.
The pH of the effluent of the wastewater treatment plant was a bit higher than the other recorded values, but not much. The effluent of the first FWS helophyte filter did show higher pH values, but here the treatment of the grey wastewater was not finished as it still had to flow through the second FWS helophyte filter.
It is not known what the temperature of the effluent of the wastewater treatment plant was, either were the dissolved oxygen, and *E.coli* concentrations known.

Concluding, the data show that the helophyte filters in Lanxmeer were able to lower the pollutant concentrations of the grey wastewater to acceptable levels during the fieldwork. The effluent of each helophyte filter showed consistent concentrations, indicating stable functioning during the two weeks and that the concentrations measured were representative for the period. On the other hand, certain effluent characteristics, such as N-total, P-total, TSS, dissolved oxygen, temperature and *E.coli*, differed per location. This shows that although the helophyte filters are similar, their performance can be different, which can be explained by the complex biological processes that take place as well as external influences such as climate.
In comparison to the effluent of the wastewater treatment plant, the effluent of the helophyte filters in Lanxmeer had lower or comparable BOD_5, COD, N-total and P-total concentrations. Only the TSS concentrations of two of the three (*School* and *Unie*) helophyte filters were higher than the TSS concentrations in the effluent of the wastewater treatment plant.
The FWS and V-SSF helophyte filters in Drielanden show similar results as the V-SSF helophyte filters in Lanxmeer, although they do have more variance. The effluent of the helophyte filters in Drielanden does have higher COD concentrations, but lower P-total concentrations. It should be noted that only two FWS helophyte filters, which threat the grey wastewater in sequence, are compared with three individual V-SSF helophyte filters. It should be noted that it is not known if these differences are consequent or that the effluent characteristics of the FWS helophyte filters are low or high compared to the effluent of other FWS helophyte filters. This is because no effluent characteristics of other FWS helophyte filters treating grey wastewater in the Netherlands were available.

The financial analysis done in section 10.2.4 showed that the annual costs of the helophyte filters are similar to the fee that the inhabitants pay to the municipality for using the sewage system. In addition, the above analyses show that during the sampling period the effluent of the helophyte filters in Lanxmeer was comparable with, or better than, the effluent of the wastewater treatment plant in Culemborg. As the fees that the inhabitants pay to the Water Board for treating their wastewater were not included in the earlier financial analysis, it seems plausible that it is cheaper to treat grey wastewater with a (V-SSF) helophyte filter and black wastewater with a wastewater treatment plant [38] (or decentralised treatment system such as an UASB reactor) than to treat all municipal wastewater with a conventional wastewater treatment plant. However, as the costs for treating black wastewater with a conventional wastewater treatment plant or UASB reactor, as well as the costs for treating the municipal

[38] Note that wastewater treatment plants in the Netherlands perform better with more concentrated wastewater streams (i.e. the black wastewater stream).

wastewater with a conventional wastewater treatment plant were not included in this study this cannot be said with much certainty. Instead it is recommended to conduct more research on this (see Chapter 12 as well).

10.2.7. Perception, Future and Recommendations

The helophyte filters are perceived as a positive addition to the neighbourhood and a good way to treat the grey wastewater. Although the inhabitants do not always show involvement with the helophyte filters and it is known that non-ecological soaps and detergents containing chlorine are used, they do appreciate their existence.
Those responsible for the operation and maintenance are also positive about the helophyte filters due to their simplicity and robustness. Nevertheless, at Portaal there is some hesitation towards the helophyte filter, which can be explained by the large investments that the Housing Corporation had to make after the neighbourhood was completed. As the helophyte filter there needs rehabilitation this is perceived as yet another expenditure for a relative small group of people.

The helophyte filters in Drielanden and Lanxmeer will stay in use as long as they function and perform properly. The largest future investment required is thought to be the renewal of the V-SSF helophyte filters in Lanxmeer when too many solids have accumulated in the beds or P is no longer removed adequately from the grey wastewater. However, it is uncertain when this will happen and how much the renovation will cost. The future investments needed at the FWS helophyte filter in Drielanden are unknown. The attitude of the municipality is that this will be dealt with when the issues emerge.
The future is uncertain for Polderdrift. Several options are possible, namely that the situation will continue as it is till large investments such as renewal of the pumps are needed; that the whole helophyte filter will be rehabilitated; or that the helophyte filter will be demolished. At the moment it seems likely that one of the first two scenarios will happen. Portaal is currently, after persuasion by the tenants' organisation, investigation how much the rehabilitation will cost. After the required investment costs are known a decision will be made.

The inhabitants and employees of the municipality and Portaal interviewed recommend the use of a helophyte filter, FWS or V-SSF, for grey wastewater treatment. Not only do they seem to perform well, but the aesthetic values, relative simple maintenance requirements and low operation and maintenance costs (excluding the renewal costs) are other positive aspects mentioned.

10.3. Developing Countries

The grey wastewater sampled in Lanxmeer is vastly different from the grey wastewater samples in Israel, Jordan, Costa Rica and Nepal. Furthermore, the grey wastewater characteristics collected from international (that is, non-Dutch and European) cases differs vastly per case as water consumption, household activities and products used differ per case. This shows that if (grey) wastewater characteristics representable of one case are transposed on another case the design criteria could be very different from the actual situation. This can result in either an over-sizing of the technology (too expensive) or under-sizing, which can result in poor performance, a short lifespan and high (financial) losses.

When using the term grey wastewater in the Netherlands one automatically includes kitchen, laundry, shower and bath and sink wastewater as these are all present in households and most offices and schools. However, in developing countries this is not the case as different activities can take place at different locations. Although showering or bathing can take place in or near the house, laundry activities could take place at a communal water collection point. Kitchen wastewater can also be produced at this communal point, but also at the household or in a centralised cafeteria as is the case in a boarding school. The spreading of these activities, and hence the different sources of the grey wastewater, has profound influence on the concentrations of pollutants in the grey wastewater, as Table 9 clearly shows.

Treating grey wastewater with a helophyte filter implies that the different wastewaters are separated at source. In case the black wastewater is collected in the building as well, separate piping systems are needed. These, as Lanxmeer showed, can be confused and interconnected. This results in the pollution of grey wastewater with the more concentrated black wastewater. This occurred in the Netherlands despite policy dictating that all connections should be double checked by different people before the sewage pipes are covered. This is likely to be a major pitfall in development projects. On the other hand, if outside toilets are constructed, the black wastewater will be collected separately by default. The type of toilet (flush toilet, VIP latrine, composting toilet) as well as the location where it is constructed (edge of village, near each house) will determine if a sewage piping system will need to be constructed and how extensive it should be.
A location that does not have flush toilets yet could very well install these within the projected lifespan of 25 years that is attributed to helophyte filters. If this is the case, not only will people install new sewage pipes, but a (potable) water distribution network might also be constructed. The latter does not have to

be in place to produce grey wastewater as people can collect the (potable) water from communal sources. When these water systems are constructed, the risk that faulty connections will be made between the different wastewater and (potable) water piping systems increases. These faulty connections can not only result in more polluted water than was anticipated entering the helophyte filter, but also in the mixing of (potable) water with wastewater in more extreme cases. This, of course, will increase the threat to public health. If the helophyte filter was designed for grey wastewater the later production of black wastewater will increase the pollutant concentrations and loads resulting in the need for larger or more helophyte filters.

All three cases analysed during this research had a large organisation such as a municipality or Housing Corporation involved in the planning and construction phases of the helophyte filter. These were later also involved with the operation and maintenance procedures. The advantage of involving a large organisation is that there generally are more means available for completing and maintaining the helophyte filter. The prerequisite for this is, of course, that this organisation will be motivated to do so. If there is no motivation the input of the organisation will be minimal and the advantage of using will be gone. In the three cases analysed in this research the organisations were motivated to implement the helophyte filters as part of the ecological and sustainable projects. However, as is demonstrated in Polderdrift, the declining motivation of an organisation for investing in the helophyte filter results in a deterioration of the helophyte filter with the eventual risk of having to shut it down. Hence, once a helophyte filter is constructed, it is critical that the organisation that is responsible for the operation and maintenance of the helophyte filter stays motivated to fulfil these procedures.

In the above section and in the three cases analysed in this research the organisation responsible for the operation and maintenance procedures is a rather large institution, which does not always have to be the case. In developing countries a small group of people, usually local users, can be more effective than a large institution. Here, it would be possible to form a (formal or informal) users' organisation (perhaps called Helophyte Filter Users' Association; HFUA) that consists of motivated people that is responsible for organising the (basic) construction materials such as gravel and sand, labour and to provide a piece of (communal) land where the helophyte filter can be constructed. This can not only save costs but also give the users a sense of ownership. This HFUA, which could even consist of a just few motivated individuals, could also organise the operation and maintenance procedures. If the HFUA is too small to perform certain actions, such as mowing, they could persuade other users to help or hire labourers from the fee that the users pay.

In Drielanden and Lanxmeer the municipalities were part of the original planning of the neighbourhoods and were enthusiastic about the ecological and sustainable objectives. Their enthusiasm resulted in a commitment to operate and maintain the helophyte filters. This commitment seems to be less in Polderdrift, which could be related to the current Housing Corporation, Portaal, not being part of the group that formulated the original ideas for the neighbourhood. They, instead, later acquired the project, which in combination with the high costs needed to repair different aspects of the houses and helophyte filter, could be reason for less enthusiasm and commitment.
The same basic principle can be seen and applied to cases from the developing world. If a local community does not perceive the treatment of wastewater as necessary, the implementation of any wastewater treatment technology will be in vain if this community has to operate and maintain it. Thus it is of critical importance that the users see the need for a helophyte filter and are willing to invest in it, not only on initial construction but also in the operation and maintenance aspects.

The design of the helophyte filter, as mentioned earlier, should take possible future scenarios into account. Not only can influent composition change with new developments such as new household products and more flush toilets, but the number of inhabitants (p.e.'s) can increase as well, thereby increasing the wastewater stream. On the other hand, the current situation will dictate the layout of the helophyte filter and whether aspects such as pumps will be used. During the design the presence of a reliable energy source as well as spare parts, transport of these parts and knowledge about the operation and maintenance requirements should be considered. If this is not done the helophyte filter design might be very state-of-the-art, but it will last till the first problems start to arise. The malfunctioning of aspects such as pumps or the flooding of the helophyte filter should also be incorporated into the design to make sure that the chance of something malfunctioning is minimised and that when it does happen, it will not affect the whole system.
The landscape around, and location of, the helophyte filter should also be planned carefully. Not only can the nuisance of noxious odours be minimised this way, but weed invasion can be minimised, access for operation and maintenance purposes optimised and future scenarios such as urban expansion and population increase can be taking into account.

In the Netherlands the operational and maintenance aspects of a helophyte filter are not complicated, although knowledge on what needs to be done, and how, is required. This is because the knowledge and means to perform the procedures are generally present with the company designing the helophyte filter as well as in the Dutch guidelines (see Appendix 4 as well). Nevertheless, if these are not present,

aspects such as maintaining or repairing a pump or mowing the macrophytes and maintaining the infiltration capacity can prove to be difficult. When this is the case it is likely that the operational and maintenance procedures will not be carried out properly, or not carried out all. This does not have to be out of purposeful neglect, but could also be a case of not knowing what to do.
Operational and maintenance procedures can be conducted a lot of enthusiasm and be learned by trial and error, but this will not always be good for the overall state of the helophyte filter, as Polderdrift has shown. Another example of this was the decision to burn the macrophytes growing in a FWS helophyte filter in the Netherlands rather than mowing them. Although with less input the result was the same as mowing (no macrophytes), the consequence was dramatically different and the whole helophyte filter was destroyed. [39] Instead, a good design and proper training in combination with an organisation of users that is responsible for the helophyte filter can minimise these scenarios.

Although the cost-analysis is based on Dutch figures, some general lessons can be drawn from this analysis. Of the total annual costs per household that the municipality spent on the three helophyte filters in Lanxmeer four per cent was used for operational costs, 28 per cent of the money was used for maintenance purposes, 30 per cent for renewal costs and 38 per cent for the maintenance of the four sewage systems needed to collect and transport the different wastewaters. As can be seen, the maintenance costs for the sewage systems was the most expensive aspect of the helophyte filters in Lanxmeer, but this can be different in situations where the sewage systems less extensive or where only one or two sewage systems are installed. When assuming that only one sewage system is installed the cost division will change: The operational costs form 6 per cent of the total budget, the maintenance costs 38 per cent, the renewal costs 43 per cent and the sewage system 13 per cent.

The construction of a helophyte filter, as discussed in section 10.2.4, can be expensive. This differs per case due to the unique designs, size as well as location. The helophyte filters constructed in Lanxmeer cost about €670.- per p.e., even though these were relative large, they only treat grey wastewater (for domestic wastewater the surface area of the helophyte filter will need to be twice as large) and the designs were straight forward making construction simple. Although costs can be saved by making the design more basic and making use of resources locally present, the construction of a helophyte filter will be difficult to finance for a (rural) community in a developing country as it could cost more than a persons' average annual income.

The operational costs, consisting of electricity to run the pumps and the phone bills of the phones used to notify the operators of malfunctioning, were the lowest annual costs of the helophyte filters in Lanxmeer. This does not have to be the same in a developing country, but it can be used as an indication of what to expect financially. If a helophyte filter is implemented in a developing country, these costs could be lowered although this will depend on the availability of reliable energy sources and communication networks as well as the location of the helophyte filter. The availability of skills to operate and maintain the pumps as well as spare parts to fix the pumps should also be taken into account. Nevertheless, if no pumps are installed there will be no or very little electricity requirements. Furthermore, instead of using a phone for error notifications the whole system could periodically be checked manually. This will result, however, in more labour costs.

The maintenance costs of the helophyte filter were the second highest annual costs in Lanxmeer. These costs consist of weeding and replacing gravel (41 per cent) as well as maintaining the pumps (26 per cent) and mowing the macrophytes and discarding the clippings (11 and 22 per cent, respectively). If an aggressive macrophyte species is planted in the helophyte filter less weeding will have to be done. At the same time, the landscape around the helophyte filter can be designed in such a way that the invasion of weeds and accumulation of debris and plant matter in the bed can be minimised. By reusing the clippings for, for instance, papermaking, pressing them into bricks for heating or using ornamental flowers as macrophytes an income can be generated. These decisions can result in maintenance costs that are up to 60 per cent lower. If pumps are not used in the system these will also not have to be maintained thereby lowering the operation and maintenance costs even more. Hence the operation and maintenance costs of a helophyte filter do not have to be high, but this depends on how basic the design is as well as if any income generating activities related to the helophyte filter are conducted.
The maintenance of the sewage system is based on a sewage system that is 2 km long and cleaned every 7 to 8 years. The length of the sewage system as well as the periodic cleaning, if even done at all, will differ from case to case. This expenditure can be higher in the field if the sewage system clogs a lot and pipes are broken, but it can also be much lower if the sewage system is shorter and requires less maintenance. Hence the only conclusion that can be drawn is that the sewage system does require a certain amount of maintenance and that this can be a substantial part of the annual budget.

The highest annual costs of the helophyte filters in Lanxmeer were the renewal costs. Although these are not always included in the financial picture (as was the case in Polderdrift), the renewal of a helophyte

[39] The macrophytes of a FWS helophyte filter in Flevoland were once burned instead of mowed as this was thought to be easier and cheaper. The result, however, was that all macrophytes died, thereby destroying the whole helophyte filter (Blom, 2011).

filter will eventually be necessary, unless it is discarded of. The renewal costs, like the construction costs, will be determined by local conditions and the design of the helophyte filter. If, as described in the previous paragraph, the helophyte filter is designed to be simple and the clippings are reused the renewal costs (that have to be saved for during the lifespan of the helophyte filter) can be more than half of the annual costs related to using a helophyte filter for wastewater treatment. The construction or renewal costs can be lowered if the community provides the land as well as the manual labour and gravel required for the helophyte filter. In a scenario taken from a developing country a donor will most likely be financing the construction costs. Nevertheless, these construction costs can be considerable. In addition, it is not always certain who will pay for the large maintenance requirements or renewal costs. Although it can be difficult to convince certain cultures of the relevance and importance of saving money for future (unxpected) maintenance requirements, a solution to these scenarios will need to be thought of at the beginning of the project.

As the analysis of the influent and effluent of the helophyte filters in Lanxmeer has shown, similar helophyte filters located in the same neighbourhood, treating similar grey wastewater and being operated and maintained properly can differ in their performance. The reason for this is unknown but it can be related to the complex processes that take place in the helophyte filter. If similar helophyte filters perform differently in the same neighbourhood, the assumption that they will perform in de developing country, with complete different conditions, like they do in a Western country is not plausible. Not only are the perceptions of the people different, but the traditions, norms and values, principles, perception of time and worldviews cannot be assumed to be similar to those in the western countries. The technology will need to be translocated to the new situation, and will need to be adapted to the different culture and conditions. The helophyte filter as a technology itself allows for this, but there are barriers such as costs and operation and maintenance requirements that will need to be crossed first.

The analysis in this section, which is based on the findings of the three Dutch cases as well as literature, shows that there are several pitfalls related to implementing helophyte filters in developing countries. As stated above, from a technological viewpoint the helophyte filter seems to be suitable for implementation in a developing country, although depending on local conditions and the objectives of the technology other wastewater treatment technologies might be more suitable. However, when implementing a helophyte filter the initial construction costs are the first pitfall. These can be too high for a local household or community to finance. The second and third pitfalls are who will be responsible for the functioning of the helophyte filter and who will perform the operational and maintenance procedures. Whether this is done by one person, a group of people or a large organisation, it is of critical importance that there is enough motivation and knowledge to ensure that the helophyte filter is properly operated, maintained and controlled. If these procedures are not conducted properly the helophyte filter will deteriorate and no longer meet the (initial) objectives. Lastly, the need to save for future (unexpected) maintenance costs as well as the eventual renewal of the helophyte filter can form a pitfall as well. The need to save for maintenance or renewal costs that might occur in the (far) future can be difficult for a local community to perceive. This can be related to their culture, where for example in most (Sub-Saharan) African cases, the perception of future can range to a maximum of 6 moths to 2 years (Mbiti, 1990). This could be less of an issue in other cultures. Furthermore, the need for a community to save for uncertain future costs when there are more important costs at that time will also be difficult, if not impossible, to accept. It might even seem completely absurd to do so.

Concluding, the implementation of helophyte filters in developing countries for wastewater treatment is not as straight forward as is often perceived. Instead, there are several pitfalls, each of which is of critical importance for the proper functioning and performance of the helophyte filter. If one of the previously mentioned pitfalls is not adequately overcome there is a reasonable chance that the helophyte filter will eventually degrade and stop functioning and performing according to the objectives established when it was first implemented.

11. Conclusions

11.1. Grey Wastewater

The grey wastewater literature study shows that grey wastewater characteristics can differ per location, sampling period and source. Although for a helophyte filter this variance is lessened as the grey wastewater is mixed in the grease trap, collection tanks or pumping tanks, it does mean that a design from one location, based on certain grey wastewater characteristics, simply cannot be used in another country. Furthermore, as Sneek showed, the grey wastewater characteristics can also differ per sampling period, indicating that results from one sampling period might not be representative for the general situation.
The grey wastewater characteristics of Jordan show that in one country the grey wastewater can either be diluted or very concentrated. As a result, the use of national averages can be devastating as the wastewater that needs to be treated could be much more concentrated, or diluted, than was assumed. In the latter case the wastewater treatment technology will be oversized, resulting in too high construction costs, whereas in the first case the wastewater treatment technology will be undersized, which can result in poor functioning and performance.
The sampling of grey wastewater in Lanxmeer showed that the grey wastewater characteristics were quite consistent per sampling point and throughout the two weeks of field work. There was some variance in the data between the different sampling locations (*Station*, *School* or *Unie*).

These findings show that it is important to determine whether the grey wastewater characteristics are representable for the location whose grey wastewater will be treated, or if they are figures based on national averages, samples collected in different time periods or seasons, or if the data comes from samples collected at another location. The latter four cases could result in a poor design of the wastewater treatment technology as the grey wastewater characteristics being used might not be representable. The findings also show the danger of implementing a wastewater treatment technology in a different region or country that is based on grey wastewater characteristics of a different region or country.

11.2. Cases

The FWS helophyte filters in Drielanden seem to be working fine. Although the inhabitants hardly notice it, the municipality routinely checks, operates and maintains the helophyte filters. The municipality is positive about the helophyte filters due to the perception that it treats the grey wastewater well, the perception that it is cheap and simple to operate and maintain and the perception that it is a nice aesthetic addition to the neighbourhood.

The V-SSF helophyte filter in Polderdrift is not functioning properly as little effluent is produced. Due to the high investments that the Housing Corporation had to make in the neighbourhood shortly after it was completed it is not clear if the helophyte filter will be renovated or discarded. The tenants prefer the first option, but the Housing Corporation seems to be hesitant as it is the most expensive. Although the Housing Corporation is the owner of the helophyte filter and responsible for the operational and maintenance procedures, the tenants of the neighbourhood also perform some of these actions. This might be cheaper as these tenants are not paid to perform certain activities, such as mowing the macrophytes, but a side effect is that more people, with different opinions, knowledge's and experiences have a relative large influence on the state of the helophyte filter. This results in different opinions about how the helophyte filter should be maintained. Furthermore, as new inhabitants move into the neighbourhood the use and maintenance of the helophyte filter becomes less relevant for the new inhabitants and they are, generally speaking, less motivated to invest time and energy in the maintenance of the helophyte filter. These aspects seem to have resulted in a less optimal context in which the helophyte filter has to be operated and maintained and this is reflected in its current state.

The V-SSF helophyte filters in Lanxmeer function and perform well. This is shown by the data collected during the fieldwork as well as the interviews held with the different stakeholders. Not only are the users positive about the helophyte filters, but the municipality of Culemborg is as well. The municipality has decided to keep maintaining and operating the helophyte filters even though the maintenance costs were higher than expected. This also demonstrates their commitment to the helophyte filters. It is not known what large maintenance procedures will be required in the future, but it is thought that this will be the replacement of the gravel layers and filtration sand. Depending on how much this will cost the municipality will then decide what it will do. The inhabitants of Lanxmeer are positive about the helophyte filters and accept the occasional noxious odours that are produced several times per year as 'part of the package'.

11.3. Helophyte Filters

Based on this research, it can be concluded that helophyte filters are very well capable of treating grey wastewater on neighbourhood scale in the Netherlands as the effluent complies to the permits for discharging effluent to surface water bodies. Furthermore, the effluent of the helophyte filters in Lanxmeer is similar to that of a wastewater treatment plant in Culemborg. However, there are several boundary conditions that have to be adhered to.

The helophyte filters were constructed as part of projects with high ambitions. At each of these projects stakeholders were motivated to meet the objectives formulated. The large stakeholders (municipality and Housing Corporation) were able to finance the construction of the helophyte filters as they made a profit from selling land, got some of the money back from selling the houses, found donors for the helophyte filter and invested in the neighbourhood as it was an 'ecological' project. The municipalities of Groningen and Culemborg were also able to organise the operation and maintenance of the helophyte filters as they had the means to do this. In Polderdrift, however, the Housing Corporation had fewer incentives to invest in the required renewal of the helophyte filter as they had made other investments in the neighbourhood and helophyte filter shortly after construction was completed.

During the design and construction it should be kept in mind that if problems occur with the helophyte filter once it is completed, they can be very expensive to solve. Aspects such as the impermeable layer under the medium should be of high quality as a leaking helophyte filter will be expensive to repair. The choice of medium should be made carefully as well. Dutch guidelines now dictate a certain particle size for the filtration sand to allow for good filtration characteristics while ensuring good infiltration rates and capacities as well. These guidelines are not yet in place for developing countries, and when designing a helophyte filter there the particle size should be of the right size.
The requirements for cleaning the top layer from litter, checking the distribution pipes for loose fittings and blockages and removing weeds can all be simplified or complicated by the design of the landscape in which the helophyte filter is constructed, as well as the type of macrophytes and construction materials used.
The organisation of the operation and maintenance procedures, with the different responsibilities, should be clear for the users as well as those responsible for the helophyte filter. Those performing the procedures should have the knowledge about what they need to do, and why, to ensure that the helophyte filter is operated and maintained properly. This, for instance, can be done by a training and handbook.

After a helophyte filter is constructed it will always need some tinkering to make sure that all components work together optimally. Aspects such as pumping regimes will need to be adjusted and macrophyte growth will need to be monitored and potential preferential flows will need to be prevented. The construction of a helophyte filter should not be considered finished once the last pump is installed or macrophyte is planted, but when the macrophytes are settled and growing well, the wastewater is properly distributed throughout the helophyte filter and satisfactory effluent is produced.

The operation and maintenance requirements of a helophyte filter in the Netherlands are relatively simple to perform, although the amount of labour that is required can be substantial. The annual mowing of the macrophytes and periodic inspection of the system is not difficult and should not be too expensive (although this is relative to the local standards, of course), but in Lanxmeer the weeding and renewal of gravel cost more than anticipated. In the latter case as well, the total operation and maintenance costs of the V-SSF helophyte filter, including renewal costs and sewage system maintenance, were comparable to the costs of maintaining the conventional sewage system. This shows that a helophyte filter is not per se cheap to use for wastewater treatment, but that it seems to be a viable alternative for grey wastewater treatment in the Netherlands. The quality of the design and construction does have influence on the eventual operation and maintenance costs.

As the case in Lanxmeer showed, helophyte filters that were designed with the same parameters and constructed in similar ways with similar materials can still function and perform differently. This not only indicates that the functioning and performance of helophyte filters is unpredictable to a certain degree, but also that the costs needed to operate and maintain the helophyte filter can vary per situation.

The inhabitants using the helophyte filter are generally positive about them. The helophyte filters have a high aesthetic value for them and the few days a year that a noxious odour is produced are accepted as part of the technology. However, it seems that inhabitants are not, or very little, willing to compromise on living comfort and standards, meaning that during design the use of ecological detergents cannot be assumed. During fieldwork several inhabitants showed interest in the work as well as the helophyte filters, indicating that there is a certain amount of social involvement with the helophyte filters. This awareness of the helophyte filters for grey wastewater treatment is necessary as it could not only prevent wrong connections between the sewage systems being made when people are modifying their houses, but this awareness could also influence what products the inhabitants flush through the sinks.

Although the use of certain chemicals can harm the processes taking place in the helophyte filter, no instances of this happening have been recorded.
It should be noted that if wastewater streams are collected separately in a neighbourhood (even in the well organised Dutch situations), modifications that involve the sewage systems are prone to problems as faulty connections can easily be made by uninformed people. During construction this should also be checked and perhaps the use of specific construction materials (material, size, colour) for specific sewage systems is needed.

Concluding, although the helophyte filters described and analysed generally improve the quality of the grey wastewater to well within the standards set by Dutch legislation, they do remain complex biological treatment technologies that require careful design and construction as well as periodic checks and maintenance to prevent malfunctioning. The design and state of a helophyte filter influences much the operational and maintenance requirements as well as how high these costs will be.

11.4. Developing Countries

When implementing a helophyte filter in a developing country, the design, location, construction and operation and maintenance requirements should be tailored to the specific location. Although the helophyte filter itself, if properly designed, can treat the wastewater well in tropical conditions (it is thought this will even be better than in the colder climates due to the higher biological activity (Dallas *et al*., 2004; Kivaisi, 2001)), there are several crucial pitfalls that need to be addressed if successful implementation and further use of this helophyte filter is desired.

The first identified pitfall is the construction costs of the helophyte filter and the piping systems needed to collect the wastewater and transport the effluent to a location where it is discharged or used. Although the construction costs could be lower in rural areas where more land is available, the land price in urban areas is high, making the helophyte filter expensive. However, in the latter situation more wastewater is produced in a relatively densely populated area, making the need for wastewater treatment important. As a result, a helophyte filter is most applicable in rural areas or on the fringes of urban areas, although this can differ per situation. In very densely populated areas the space is simply lacking and other wastewater treatment technologies will generally be cheaper to construct. It should be noted that due to the space requirements of a helophyte filter, it is an option to construct one on the fringes of an urban area and then selling the land again after 20 years when the helophyte filter needs to be renewed. Due to the urban expansion the land prices will have increased, thereby generating a profit that can be used to install another wastewater treatment technology (Huibers, 2011).

The second pitfall is who will be responsible for the helophyte filter. If there are enough funds to construct a helophyte filter, which in developing countries generally comes from external donors, it is not a given fact that the organisation constructing the helophyte filter will also be responsible for the functioning and performance of the helophyte filter. Hence it should be clear who is responsible to ensure that if the helophyte filter for some reason does not function as required, it will be checked and fixed. Furthermore, the periodic checks, analysis of influent and effluent samples and the contacts with the users are some of the procedures that need to be performed. This responsibility requires a sense of ownership and motivation and could be carried by a motivated user or group of users, for instance. This motivated group could also collect the users' fees to pay for the operational and maintenance procedures as well as save money for eventually renewing the helophyte filter (see next to paragraphs as well). If the treating of wastewater with a helophyte filter is not perceived as necessary by those responsible for the helophyte filter, it is doubtful if the helophyte filter will be monitored properly and action will be taken if required.

The third pitfall, which is closely related to the previously mentioned pitfall, is the performance of the operational and maintenance procedures. The proper conductance of these procedures is essential for the proper functioning of a helophyte filter. As these need to take place periodically enough motivation to perform these is needed. This motivation or enthusiasm is not the only requirement as there should also be enough knowledge, capacity and tools to perform the operation and maintenance procedures properly. This can be eased by incorporating the local capacities into the design of the helophyte filter (i.e. not using pumps if spare parts are hard to find, designing the helophyte filter in such a way that no large equipment is required for maintenance if this is not present or available), which will result in a helophyte filter that is tailored to the specific location and locally available resources, cultures, traditions and capacities. This, with the motivated people that are responsible for the functioning, operation and maintenance procedures will increase the likelihood that the helophyte filter will function and perform properly till it needs to be renewed.

The high financial cost related to renewing the helophyte filter or (unexpected) large maintenance requirements is the fourth pitfall. As the different cases analysed in this research have shown, unforeseen costs have occurred at all cases. This was usually related to the tinkering required at the initial start of the helophyte filter to ensure proper functioning, but in other instances pumps had to be

repositioned, additional piping systems had to be constructed and more maintenance was required. These were all unforeseen costs that required a substantial financial investment. Furthermore, as the Polderdrift case has shown, the renewing of a helophyte filter can be quite expensive, especially if no money has been saved for this purpose. Even though these costs can be unexpected, they still need to be included in the initial construction budget if they are related to the tinkering, or be included in the user fees if they are expected to occur later, as these costs can be considerable. Furthermore, the purposes of these costs have been critical for the proper functioning and performance of the helophyte filters, showing that they cannot be ignored.
However, in certain settings from developing countries the concept of saving money for an unexpected problem in the (possibly far) future can be difficult to grasp or seem ridiculous. For example, in most (Sub-Saharan) African cases the perception of future can range to a maximum of 6 moths to 2 years (Mbiti, 1990), showing that it is impossible to convince local users of the importance of saving money for renewing a helophyte filter in 20 years. In addition, the money that they have to save could also be used for school fees, food or other immediate necessities. Nevertheless, there is a need to build up some savings. One possibility is that it is incorporated into the general users' fees, although the person or organisation responsible for this will need to understand why it is being done. Furthermore, corruption is a danger here as eventually a relative large sum of money will be saved.

Concluding, it can be stated that the implementation of helophyte filters is not as straightforward as is often perceived. Instead, there are critical pitfalls that each needs to be addressed in order to increase the chances of prolonged functioning and performance. In addition to these pitfalls, there are some other conclusions pertaining to the implementation of helophyte filters in developing countries.

The helophyte filter lends itself for other, perhaps income generating, activities. The clippings, for instance, can be pressed into bricks so that it becomes a slow-burning heat source. Another possibility is the use of the clippings in a biogas installation. Depending on the macrophytes used, the clippings could also be sold as ornamental flowers or be used for making products such as mats or fences. The helophyte filter itself can be used for educational purposes as it will attract other flora and fauna as well. Hence, by taking a wider approach the helophyte filter can not only treat wastewater, but also generate income.

Future scenarios, such as population growth, urban expansion and the introduction of new products in an area, such as flush toilets, chemicals, soaps and detergents can have an influence on the functioning and performance of a helophyte filter. Furthermore, if there are different piping systems, the installation of new sewage systems in an area or modifications made to a building can result in faulty connections between these different piping systems. This should be incorporated into the design of the helophyte filter by analysing different future scenarios, with their implications and the required performance of the helophyte filter, during the design phases. Although not all developments can be accounted for, this can result in the most optimal design for a specific location that allows for future expansions or adjustments.

11.5. Integrated Reverse Water Chain

The analysis and conclusions, in combination with the settings approach and reverse water chain concept that were explained in sections 2.2.2 and 2.2.3, show that the choice for a helophyte filter as wastewater treatment technology is not apparent as one would think. It is also shown that the design of a helophyte filter is not as straight forward as one would think, but that there are several key aspects that need to be taken into account. These are partly technical, but are often also related to social, economic and cultural aspects as well as future scenarios of the location.

These findings have led to a combination and adaption of the two earlier mentioned concepts. The result is a concept called the integrated reverse water chain, which shows a larger, integrated approach to choosing the wastewater treatment technology. Here the setting (location, culture, local capacities, economics, legislation) and the future scenarios of the situation, as well as the future use of the effluent, the characteristics of the influent and available wastewater treatment technologies have a profound influence on the choice of the wastewater treatment technology (Figure 22).

The integrated reverse water chain shows that the setting in which the helophyte filter will be placed, whether this is in the Netherlands or in a developing country, has a profound influence on its future functioning. The extent of this influence differs per situation, but by taking the setting, with the location, culture, local capacities, economics and legislation, as well as the future scenarios of the situation into account during the design phases several of the earlier mentioned pitfalls can be avoided or its impact lessened. The concept also shows that the design and construction of a wastewater treatment technology should go hand in hand with social aspects or human factors, such as the organisation and performance of operation and maintenance procedures and influence of the local setting. Although the two (society and technology) are sometimes perceived to oppose each other, the above concept shows that they can and need to work hand in hand in order to get the most effective, suitable and sustainable solution for wastewater treatment.

This is supported by a cost-benefit study by Graaf *et al*. (1997), who show that a wastewater management scenario with a closed water cycle where all wastewater is treated and where pollution is removed at the source can be very sustainable. As a result, wastewater is nolonger a source of pollution and threat to the public health, but instead the pollution of water is reduced, and if the wastewater is polluted (with controlled pollutants), it is treated according to the requirements for its next use.

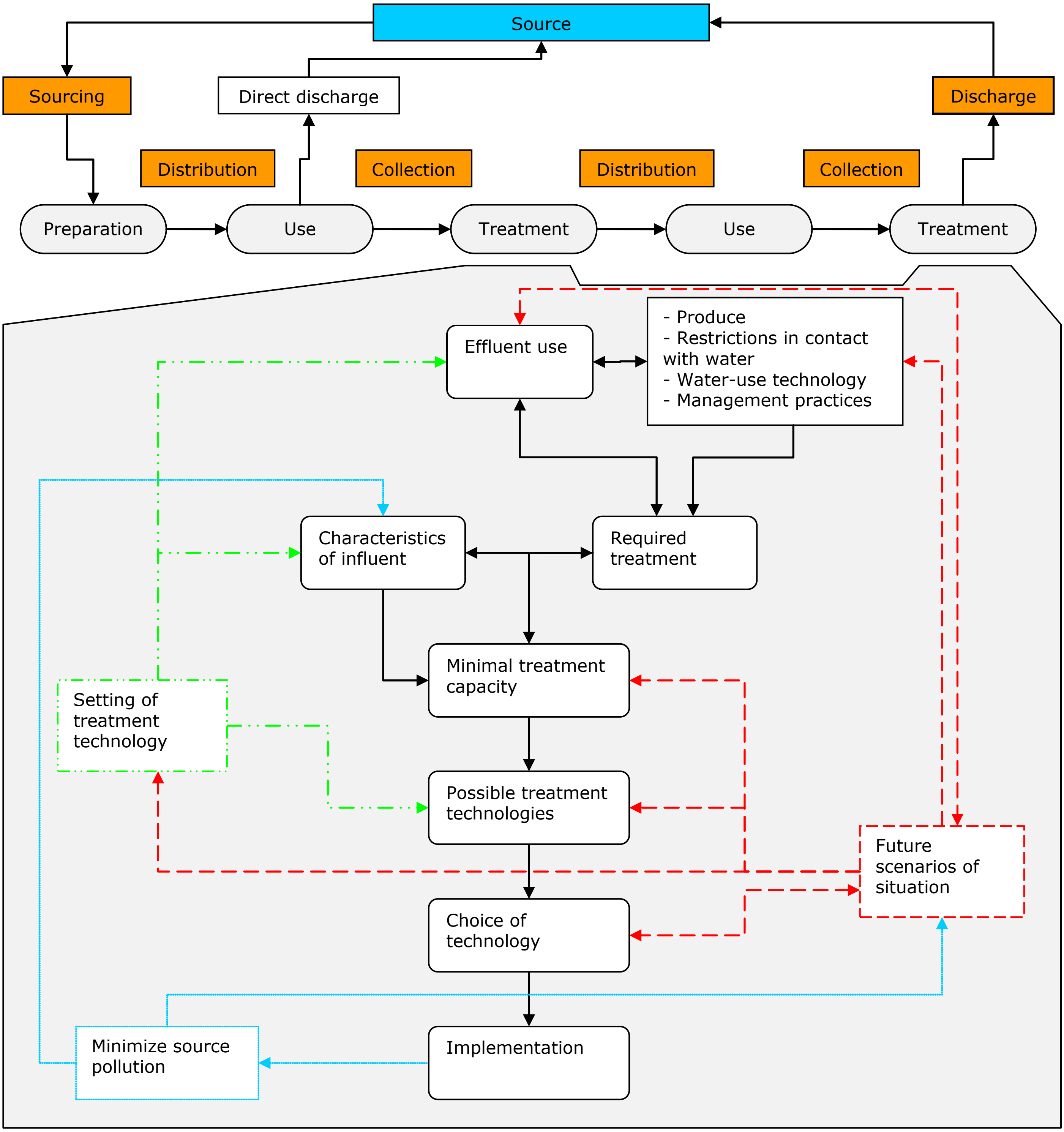


Figure 22. Integrated Reverse Water Chain

11.6. Helophyte Filters: Sense or Non-Sense?

Overall, based on this thesis research, it cannot be concluded that the use of a helophyte filter for wastewater treatment is sensible or non-sensible. Instead, and perhaps unsatisfyingly, the answer remains in the middle. Technologically speaking, helophyte filters are capable of treating grey wastewater (shown in this research) as well as domestic wastewater (based on literature). However, in order to let the helophyte filter function and perform properly there are also other prerequisites that need to be met. These are more related to the setting in which the helophyte filter is placed, as well as future scenarios of the situation.

Those responsible for the helophyte filter will need to be motivated for using the helophyte filter for wastewater treatment. A key point here is that the implementation of the helophyte filter should not continue if those who are going to be responsible for the helophyte filter do not see the need for treating the wastewater. They might want to treat the water for different reasons (effluent use, effluent discarding, public health), but the need for a wastewater treatment technology should be clear. If they do not perceive it as a necessity, the motivation to invest will be less, with all dire consequences.
In addition, those responsible for the helophyte filter should see the need to save money for future investments. Again, if this need is not seen and if a way to do this is not found the chances that the helophyte filter will eventually deteriorate are realistic.
Lastly, the implementation of a helophyte filter for wastewater treatment is not immediately sensible as there are still a lot of unknowns. It was striking that throughout the research a lot of people based their opinions and ideas on perceptions and partial information. Although a lot of the existing information, experiences and knowledge were bundled in this thesis, this is partly based on the opinions of the interviewees, thereby resulting in a certain lack of objectivity.

As a consequence, this research can simply not annotate the (conflicting) perceptions that surround helophyte filters as true or false. Instead, it is shown a helophyte filter can be sensible to implement if the different pitfalls are avoided and the setting is correct. However, if this is not the case, it will be non-sense and ultimately, waste of resources.

12. Reflection

Looking back on the research, several critical points that can be made, which relate to the methodology, the data used, the theoretical framework and the general research processes.

One critical point is that the number of interviews taken in each neighbourhood is quite low. The motivation for some statements made in this thesis would be stronger if more inhabitants would have been interviewed. This could have been done by means of a short questionnaire, for instance. In order to do this the research would have had to be less broad (i.e. less focus on grey wastewater, for instance) as the interviews would have required more time.

During a lot of the interviews the answers contained opinions that were based on perceptions and partial information. This not only resulted in a lack of objective data, but also lessened the applicability of the general lessons learned, because the perception is based on Dutch people who live in ecological neighbourhoods or work with helophyte filters as part of their profession. This large existence of perceptions, instead of more 'factual' information (i.e. recorded data, manuals, financial overviews) came as a surprise. It was expected that in the Netherlands more (factual) data on the design, construction, implementation, operation and maintenance would be (readily) available with those responsible for the helophyte filters. This, however, was not the case.[40]

The aliquots that formed the composite samples, which were used to determine the influent and effluent characteristics of the helophyte filters in Lanxmeer, were collected during the day, thereby leaving out the grey wastewater that was produced in the evening and night. This grey wastewater would have come from household activities such as washing the dishes and showering. It was not possible to collect the aliquots during the evenings and nights as I needed to prepare the composite samples, travel home, sleep, and deliver the composite samples to the lab. Although the wastewater produced in the evenings and nights was not sampled, it was collected in the grease traps and pumping tanks where it mixed with the other grey wastewater. As a result, the influence of not sampling the grey wastewater that was produced in the evenings and nights is thought to be minimal.

During the analyses, where the pitfalls for implementing helophyte filters in developing countries were determined, very little literature was used. Although literature is given when helophyte filters in developing countries were discussed (section 5.5), my main source of information was my own experiences, which I have gained over the past 18 years while living, working and learning in multiple developing countries (Sub-Saharan Africa). These are, scientifically speaking, not strong arguments, and I believe that a literature study on the implementation of development projects in third world countries, with the focus on wastewater treatment would have made my case in the analyses and conclusions much stronger.

In hindsight the theoretical framework, which came forth from two different concepts and field experiences, suited the research well. It not only allowed for an analysis of the wastewater treatment technology itself, but also for an analysis of the setting in which the wastewater treatment technology is placed. The influence and importance of the setting on the wastewater treatment technology was clearly shown in the conceptual framework. Hence it was able to look at the wastewater treatment technology without losing sight of the bigger picture. On the one side it gives space a technological story, whereas on the other side the social aspects are described.
A possible point of critique is that the concept on the one hand is too complex or in-depth in certain areas (effluent use, chain of decision making) and too vague in other areas (setting and future scenarios). For future similar research, I would recommend the use of the integrated reverse water chain concept. Nevertheless, although I spent a considerable amount of time working on the integration of the two different concepts and my field experiences, there is always room for improvement. These could perhaps consist of clarifying the setting and future scenarios more, as well as the different influences that come from these aspects. It should be noted that there is always the danger of making it too complex, and thereby not practical anymore, which is what it is initially meant to be in the first place. By letting the concept remain more general, its applicability is broadened as each user can fill in the different aspects according to the specific situation.

The current thesis, without the appendices, has become quite long. This can, generally speaking, be traced to the three chapters describing the different cases. The information about these cases was very scattered and is bundled in this research, resulting in much detail. Although this bundled information will make future research on these cases easier, it has made the thesis difficult to read. Unfortunately, this was only discovered when the thesis was almost completed and rewriting those chapters, with the

[40] The department responsible for checking permit compliance (from Water Board Noorderzijlvest) noted that it was not aware that the grey wastewater in Drielanden was being treated by a helophyte filter (Ottens, 2010). Drielanden is located about 1.5 km east of the headquarters of Water Board Noorderzijlvest.

analyses and conclusions, proved too much work for the time remaining. As a result they are left in the body of the thesis, but in looking back it would have been better if the information would have been presented in the appendices. The body of the thesis would then only have included a summary of the necessary information (in a table, perhaps), which would have made it much easier to read and analyse. The same goes for information presented in the methodology, such as how the samples were collected, as it is relevant information for understanding and using the data, but not relevant enough to be included in the actual thesis.

In hindsight, if I would have to do the same research again I would do several things differently. First, I would have made better agreements between the different parties involved. This would not only save time, as the miscommunication resulted in several delays, but also clarify the research from the beginning, which would making it more manageable. In addition, the clearer agreements would have prevented one party's wishes being overshadowed by the others', as the latter was more assertive in its communication.

Second, the decision to analyse the influent and effluent of the helophyte filters in Lanxmeer should have been made earlier. It was not clear from the beginning if this would be done or not, and as a result the Water Board Rivierenland was contacted after most of the interviews were already conducted. This led to a delay in the research as the Water Board had to find funding, a sampling programme had to be determined, the samples had to be collected and the laboratory had to perform the analyses. Also, in this case I would have advised the use of automated samplers. This will not only make the fieldwork easier, but it will also allow for flow-proportional sampling, making the data more credible and comparable. It would also allow for similar research to be done in another season to determine the influence of warmer temperatures or precipitation.

Lastly, I would have started writing the chapters on the literature and case studies as the research was going on. Although certain facts were discovered in the final stages of writing the thesis, such as the faulty connections made in the grey wastewater sewage system at a school building in Lanxmeer and opinions of the inhabitants and the Housing Corporation about renewing the helophyte filter in Polderdrift, it would have saved time if the findings would have been on paper already, instead of having to write everything at one go.

13. Recommendations

This research has led to several recommendations for future research:

- It is clear from literature and the case studies that grey wastewater characteristics vary between locations, sampling periods and sources, resulting in a lot of unknowns. In order to get a better understanding of grey wastewater composition, the influence of the different sources and how its characteristics change over time more research should be conducted on this subject. This will result in more grey wastewater data, which will enable better management and treatment. Furthermore, the data will replace the perceptions that certain decisions are now based on. The research would, for instance, consist of analyses of different grey wastewater samples taken at one location during a longer time period. Another possibility is to take more grey wastewater samples from locations throughout the Netherlands to see how they relate. Note that due to the variance in grey wastewater composite samples should be taken, not grab samples.

- Discern the different Dutch grey wastewater streams coming from a household. Thus the most polluting ones can be identified, after which adequate measures, such as possible diversion into the black wastewater stream can be thought of. This could result in a more consistent composition of grey wastewater, which can simplify its treatment and reuse options. As grey wastewater treatment is currently the most expensive part of decentralised wastewater treatment in the Netherlands, more efficient management and treatment of this wastewater stream has economic benefits as well.

- In future grey wastewater research, include the daily wastewater production. This was not done in this research as the means were not available. As a result the pollutant loads could not be calculated or compared with other cases.

- The high *E.coli* concentrations measured were not expected and came as a surprise. This could be specific to the neighbourhood, sampling period or an outlier. More research on grey wastewater characteristics should be conducted on this topic to see why these concentrations were high and what the source is.

- In future analyses include electro-conductivity as well. This is used to indicate how saline the water is, which is relevant when the wastewater, or effluent, is used for irrigation purposes as not all plants can cope well with salinity. Furthermore, as salts do not evaporate the irrigated soils can become saline, making them unsuitable for further (agricultural) use. The effect of the salinity of wastewater on a helophyte filter is thought to be less as the wastewater flows through a helophyte filter; the salts cannot accumulate in the filtration sand as they will dissolve and leave the helophyte filter via the effluent. Nevertheless, if the wastewater is saline the macrophytes will eventually not be able to function properly and could die off. This will result in a malfunctioning and deterioration of the helophyte filter. Furthermore, if salts do accumulate in the helophyte filter it will eventually have to be flushed with less saline water or might even need to be renewed. Both measures can be very expensive. In addition, the saline effluent can have a negative effect on the location of discharge.

- Analyse the influent and effluent characteristics, to calculate the removal efficiencies, and the functioning of the helophyte filters in Lanxmeer in spring (as macrophytes start to grow), summer (warm temperatures result in higher biodegradation), and autumn (the function of the macrophytes starts to decrease). These results can then be compared with the data from this thesis to learn more about the performance and functioning of a helophyte filter year-round.

- This research has shown that the effluent of the helophyte filters in Lanxmeer was of similar or better quality than the effluent of the wastewater treatment plant in Culemborg. As this research was done in the winter, it is recommended to conduct similar research in warmer circumstances such as summer. At the same time, a financial analysis should also be done to see if the use of a helophyte filter for grey wastewater treatment and a separate treatment technology for black wastewater treatment is comparable or cheaper than the current conventional Dutch wastewater treatment plants.

- Keep an eye out on the helophyte filter in Polderdrift. If this is renovated, it will not only provide insight on how much the renovation of a V-SSF helophyte filter in the Netherlands costs, but it will also provide the opportunity to analyse the current medium for P. As there are still unknowns in this area, this study can lead to a better understanding of where and how P is removed from the grey wastewater.

- The clippings from the helophyte filters in Lanxmeer (and the other cases) are currently being discarded of as waste. In the case of Lanxmeer, which is a neighbourhood trying to minimise the waste production, a study on potential reuse of these clippings (e.g. for the future biogas installation) is an interesting option. However, in order to make this financially feasible, the volume of clippings should be large enough.

- Analyse other, similar helophyte filters located in western countries and developing countries to learn more about how the functioning and performances between the two differ.

- Conduct research on the implementation, functioning and performance of helophyte filters in developing countries. Especially the implementation and success of operation and maintenance requirements, as well as the financial situation, should be analysed in order to learn more about the applicability of this wastewater treatment technology in developing countries.

- Before installing multiple wastewater treatment technologies in a certain location, determine what the likelihood is that the different sewage systems will eventually become interlinked and what the consequences of these faulty connections will be.

Part E. Acknowledgements, References and List of Interviewees

14. Acknowledgements

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Bulk, J. van den, (2010). Engineer, Tauw bv, Deventer. Personal communication, 25-8-2010.
Dijk, J. van, (2010). Inhabitant of Waterland, Drielanden, Groningen. Personal communication, 19-10-2010.
Hooijer, D., (2010). Civil technical supervisor, municipality of Culemborg, Culemborg. Personal communication, 12-10-2010.
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Part F. Appendices

Appendix 1. Interview Form

Date/Time:
Naam:
Adres:
Location of Interview:

Uitleg:

- *Eerste verkenning*
- *Andere actoren*
- *Vervolg mogelijk*
- *Interesse in verslag? [ja/nee]*

Technologie

- Grootte
- Huizen
- Wanneer aangelegd
- Wijksamenstelling/overeenkomst tussen bewoners

Actoren

- Beheerders
- Gebruikers
- Onderhoud
- Controle
- Financieel

Geschiedenis

- Initiatiefnemer/drijfveer
- Stappen tot realistatie
- Kosten/Financiering
- Wie heeft het ontworpen?
- Hoe ging de besluitvorming?
- Wie was er verantwoordelijk
- Rol van actoren
- Waar liep men tegenaan?
- Wat is aan te bevelen?

Motivatie en tegenslag

- Economisch
- Sociaal
- Milieu
- Beleidsmatig
- Financieel
- Volksgezondheid

Functioneren

- Geur
- Gebruiksvriendelijkheid
- Volksgezondheid
- Beleid
- Oppervlaktewater
- Drainage
- Kosten
- Veerkracht/robuust

Onderhoud

- Door
- Tijd
- Kosten

Toekomst

- Hoe ziet die eruit?
- Risico's van gebruik (wat is voorgekomen?)

Aanbeveling voor soortgelijke initiatieven

Verdere contacten

Actiepunten

Appendix 2. List of Materials Used for Collecting the Influent and Effluent Samples

The following list of materials was needed for collecting the samples. The provider is named in brackets behind:

- Key to access the sampling points	(Municipality of Culemborg)
- Sample collection container	(Water Board Rivierenland; 1pcs)
- Aliquot-container	(Water Board Rivierenland; 100 pcs)
- Intermediate sample container	(Water Board Rivierenland; 6 pcs)
- Final sample containers	(Water Board Rivierenland; 216 pcs)
- Cooler boxes	(Water Board Rivierenland; 3 pcs)
- Pole and clamp	(Water Board Rivierenland; 1 pc)
- Demineralised water	(Water Board Rivierenland)
- Paper towels	(Water Board Rivierenland)
- Surgical gloves	(Water Board Rivierenland)
- Squirt bottle	(Water Board Rivierenland)
- Oxygen Probe	(Wageningen UR, dep. of aquatic ecology)
- pH meter	(Wageningen UR, dep. of aquatic ecology)
- Calibration fluids	(Wageningen UR, dep. of aquatic ecology)
- Temperature logger with 4 sensors	(Tauw bv, Deventer)
- Record sheet	(Tauw bv, Deventer; 40 pcs)
- Extra batteries	(Student)
- Clamp board	(Student; 3 pcs)
- Brush	(Student)
- Tool to access sampling points	(Student)
- Flash light	(Student)
- Ice pack	(Student; 12 pcs)
- Rope	(Student)
- Tape	(Student)

Appendix 3. Costs of Fieldwork

The laboratory of Water Board Rivierenland agreed to provide all containers (collection, aliquot, intermediate and final), as well as the cooler boxes, pole and clamp, demineralised water, paper towels, surgical gloves and squirt bottle free of charge

The probes were provided by Wageningen UR free of charge.

The municipality of Culemborg provided the key to access the sampling points (influent only; effluent was freely accessible).

The temperature logger and record sheet were provided by Tauw bv, Deventer. They also compensated the transportation costs (a total of 1271 km).

The clamp boards, extra batteries, ice packs and smaller tools needed were provided by the student.

Appendix 4. Annual Operation and Maintenance Procedures of a V-SSF Helophyte Filter as Prescribed by Dutch Guidelines

Table 30. Dutch guidelines for the annual operation and maintenance procedures of a V-SSF Helophyte Filter (VROM and KIWA, 1998)

Activity	Frequency	Action
Effluent collection/pumping tank	Weekly	Visual check of effluent (clear and odourless)
Influent collection/pumping tank	Weekly	Visual check of influent collection tank for accumulated sludge and debris
Pumping controls	Weekly	Ensure proper functioning and switches
Overall system	Weekly	Check overall state of system
Macrophytes	Weekly	Monitor growth and development of macrophytes. Growth should be uniform. Remove weeds if these are present
Freezing	Weekly	During cold temperatures, make sure that the helophyte filter does not freeze by temporarily covering it with agricultural plastic if necessary
Grease trap	Quarterly	Check grease trap for sludge accumulation. Remove this if present.
Overall helophyte filter	Quarterly	Check overall condition of the helophyte filter
Bunds	Quarterly	Check the bunds around the helophyte filter for erosion
Influent distribution	Quarterly	Make sure that the influent is distributed uniformly. If needed, remove end caps of the distribution piping system while the pumps are running to flush the pipes.
Septic tank	Semi-annually	Check the septic tank for a sludge layer (this should not be hard as it indicates a disturbance in the equilibrium between sludge production and deterioration). This sludge, with the floating layer, should compromise not more than 30 per cent of the total depth.
Service of system	Annually	The whole system (from where the wastewater is collected to where the effluent is discharged) needs to be checked, maintained and serviced by the person who installed it, possibly with the user.

Appendix 5. Effluent Characteristics Measured During a Study by C-mark in Polderdrift, Arnhem

Table 31. Effluent characteristics as measured by C-mark in Polderdrift, Arnhem (Betuw, 2005)

	Units	Effluent collection tank
Aggressive carbonic acid (CO_2)	mg/l	2.03
Carbonic acid (CO_2)	mg/l	6
Hydrogen carbonate (HCO_3)	mg/l	120
Chlorine (Cl)	mg/l	11
Sulfate (SO_4)	mg/l	10
Calcium (Ca)	mg/l	65
Iron (Fe)	mg/l	0.37
Manganese (Mn)	mg/l	<0.01
Saturation index (SI)		-0.11
Electro conductivity	mS/m	23
Acidity	pH	7.55
Temperature	°C	19
E.coli	cfu/100ml	250
Aeromonas species (30°C)	cfu/100ml	80

Appendix 6. Weather Conditions During Fieldwork (22-1-2011 till 4-2-2011)

Table 32. Temperature, precipitation and wind chill equivalent temperatures conditions during fieldwork period (Data from weather station Herwijnen)

Date	Sample type Collected	Temperature[1]			Wind Chill Equivalent Temperature[A]			Total Daily Precipitation[1]
		Mean	Min	Max	Mean	Min	Max	
		°C	°C	°C	°C	°C	°C	mm
24-1-2011	Influent	5.3	4.1	6.9	-0.9	-2.8	1.1	1.0
25-1-2011	Influent/Effluent	4.1	-0.4	6.2	-3.5	-7.9	-1.4	3.6
26-1-2011	Influent/Effluent	0.8	-1.3	3.8	-4.6	-8.3	-0.2	0.8
27-1-2011	Effluent	0.1	-2.1	1.7	-8.3	-11.3	-6.6	0.0
28-1-2011	None	-2.0	-3.8	0.7	-10.4	-13.5	-6.6	0.0
29-1-2011	None (Weekend)	-3.3	-6.4	0.8	-11.2	-14.4	-6.3	0.0
30-1-2011	None (Weekend)	-2.2	-5.8	0.6	-9.8	-14.7	-5.8	0.0
31-1-2011	Influent	-1.9	-3.1	-1.2	-7.9	-9.9	-5.8	0.0
1-2-2011	None (Illness)	-1.4	-3.7	1.4	-10.3	-14.3	-6.8	0.3
2-2-2011	Influent/Effluent	2.9	1.5	4.1	-5.2	-6.3	-3.9	0.0
3-2-2011	Influent/Effluent	5.0	2.9	7.0	-2.5	-5.1	0.2	2.2
4-2-2011	Effluent	8.5	5.6	10.1	0.0	-2.8	2.6	0.3

Sources:
1: MeteoConsult, 2011

Notes:
A: $T_{we}=13.12+0.6215T-11.37(3.6V)^{0.16}+0.3965T(3.6V)^{0.16}$, where T is measured temperature (°C) and V is measured wind speed (km/hr.). T_{we} is in °C (KNMI, 2011).

Appendix 7. Characteristics of Potable Water Supplied During Sampling Period

Table 33. Characteristics of potable water supplied during sampling period as provided by Vitens nv (2011)

Location:	Rijksstraatweg 47, Culemborg (Pumping station Nieuwbouw)		
Type:	Potable Water Supplied		
Date	**Parameter**		**Measured Value**
2-2-2011	NO_2	mg/l	0.02
2-2-2011	NH_4	mg/l	<0.03
2-2-2011	Ca	mg/l	74.8
2-2-2011	Fe	mg/l	0.028
2-2-2011	CO_2	mg/l	6.2
2-2-2011	Mg	mg/l	5.86
2-2-2011	Mn	mg/l	<0.005
25-1-2011	Turbidity	FTU	0.14
2-2-2011	Turbidity	FTU	<0.1
25-1-2011	Dissolved O_2	mg/l	10
2-2-2011	Dissolved O_2	mg/l	9.9
25-1-2011	pH	-	7.9
2-2-2011	pH	-	7.95
25-1-2011	Temperature	°C	11.3
2-2-2011	Temperature	°C	10.6
25-1-2011	Coliform/*E.coli*	cfu/100 ml	<1
2-2-2011	Coliform/*E.coli*	cfu/100 ml	<1
2-2-2011	Electro conductivity	dS/m	0.0408
2-2-2011	Water Hardness	mmol/l	2.11

Appendix 8. Measured BOD_5, COD, TKN, NO_3^-, NO_2^-, NH_4^+, P-total, TSS and *E.coli* Concentrations in Influent and Effluent at *Station*

Table 34. Characteristics of influent at *Station*

Composite Sample Label	Laboratory Code	BOD_5	COD	TKN	NO_3^-	NO_2^-	NH_4^+	P-total	TSS	*E.coli*
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	cfu/100ml
Station-Influent-24-1-2011	2011-001685	160	295	10.3	<0.05	<0.01	5.4	3.2	62	982500
Station-Influent-25-1-2011	2011-001699	145	315	10.8	<0.05	<0.01	5.3	3.8	61	1387500
Station-Influent-26-1-2011	2011-001830	165	295	11.1	<0.05	<0.01	5.1	4.3	48	1445000
Station-Influent-31-1-2011	2011-001900	180	375	12.2	<0.05	<0.01	6.1	5.0	65	1100000
Station-Influent-2-2-2011	2011-002470	195	315	11.1	0.13	<0.01	5.8	5.3	58	2490000
Station-Influent-3-2-2011	2011-002536	150	315	11.0	<0.05	<0.01	5.6	5.2	52	1232500
	n:	6	6	6	6	6	6	6	6	6
	Mean:	166	318	11.1	<0.06	<0.01	5.6	4.5	58	1439583
	STD:	19	29	0.6	0.03	0.00	0.4	0.8	6	542815
	Min:	145	295	10.3	<0.05	<0.01	5.1	3.2	48	982500
	Max:	195	375	12.2	0.13	<0.01	6.1	5.3	65	2490000

Table 35. Characteristics of effluent at *Station*

Composite Sample Label	Laboratory Code	BOD_5	COD	TKN	NO_3^-	NO_2^-	NH_4^+	P-total	TSS	*E.coli*
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	cfu/100ml
Station-Effluent-25-1-2011	2011-001700	1.2	19	0.8	<0.05	<0.01	0.3	0.1	13.0	162
Station-Effluent-26-1-2011	2011-001831	<1.0	16	0.7	<0.05	<0.01	0.4	0.2	13.0	110
Station-Effluent-27-1-2011	2011-001873	<1.0	14	0.5	<0.05	<0.01	0.3	0.1	12.0	<15
Station-Effluent-2-2-2011	2011-002471	1.4	14	0.6	<0.05	<0.01	0.3	0.1	12.0	38
Station-Effluent-3-2-2011	2011-002537	<1.0	15	0.7	<0.05	<0.01	0.3	0.2	13.0	15
Station-Effluent-4-2-2011	2011-002546	<1.0	13	1.4	<0.05	<0.01	0.3	0.1	6.6	<15
	n:	6	6	6	6	6	6	6	6	6
	Mean:	<1.1	15	0.8	<0.05	<0.01	0.3	0.1	11.6	59
	STD:	0.2	2	0.3	0.00	0.00	0.0	0.0	2.5	62
	Min:	<1.0	13	0.5	<0.05	<0.01	0.3	0.1	6.6	<15
	Max:	1.4	19	1.4	<0.05	<0.01	0.4	0.2	13.0	162

Appendix 9. Measured BOD_5, COD, TKN, NO_3^-, NO_2^-, NH_4^+, P-total, TSS and *E.coli* Concentrations in Influent and Effluent at *School*

Table 36. Characteristics of influent at *School*

Composite Sample Label	Laboratory Code	BOD_5	COD	TKN	NO_3^-	NO_2^-	NH_4^+	P-total	TSS	*E.coli*
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	cfu/100ml
School-Influent-24-1-2011	2011-001686	185	335	22.0	<0.05	<0.01	15.6	3.6	57	1570000
School-Influent-25-1-2011	2011-001701	155	320	22.0	<0.05	<0.01	20.9	3.4	59	1387500
School-Influent-26-1-2011	2011-001832	205	340	22.0	<0.05	<0.01	12.0	3.6	52	517500
School-Influent-31-1-2011	2011-001901	180	365	20.0	<0.05	<0.01	11.8	3.4	63	982500
School-Influent-2-2-2011	2011-002472	185	315	31.0	<0.05	0.02	23.0	4.8	61	702500
School-Influent-3-2-2011	2011-002538	170	330	28.0	<0.05	0.01	19.5	4.0	53	630000
	n:	6	6	6	6	6	6	6	6	6
	Mean:	180	334	24.2	<0.05	<0.01	17.1	3.8	58	965000
	STD:	17	18	4.3	0.00	0.00	4.7	0.5	4	430401
	Min:	155	315	20.0	<0.05	<0.01	11.8	3.4	52	517500
	Max:	205	365	31.0	<0.05	0.02	23.0	4.8	63	1570000

Table 37. Characteristics of effluent at *School*

Composite Sample Label	Laboratory Code	BOD_5	COD	TKN	NO_3^-	NO_2^-	NH_4^+	P-total	TSS	*E.coli*
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	cfu/100ml
School-Effluent-25-1-2011	2011-001702	<1.0	11	0.8	11.8	0.02	0.51	1.0	<2	519
School-Effluent-26-1-2011	2011-001833	<1.0	13	0.7	10.0	0.02	0.60	1.0	<2	549
School-Effluent-27-1-2011	2011-001874	<1.0	12	0.6	10.8	0.02	0.46	1.1	<2	556
School-Effluent-2-2-2011	2011-002473	<1.0	11	0.5	11.9	0.03	0.14	1.4	<2	1409
School-Effluent-3-2-2011	2011-002539	<0.1	13	0.7	12.5	0.03	0.14	1.4	<2	2150
School-Effluent-4-2-2011	2011-002547	<1.0	17	<0.1	13.1	<0.01	0.06	1.3	<2	390
	n:	6	6	6	6	6	6	6	6	6
	Mean:	<0.9	13	<0.5	11.7	<0.02	0.32	1.2	<2	929
	STD:	0.4	2	0.3	1.1	0.01	0.23	0.2	0	702
	Min:	<0.1	11	<0.1	10.0	<0.01	0.06	1.0	<2	390
	Max:	1.0	17	0.8	13.1	0.03	0.60	1.4	<2	2150

Appendix 10. Measured BOD_5, COD, TKN, NO_3^-, NO_2^-, NH_4^+, P-total, TSS and *E.coli* Concentrations in Influent and Effluent at *Unie*

Table 38. Characteristics of influent at *Unie*

Composite Sample Label	Laboratory Code	BOD_5	COD	TKN	NO_3^-	NO_2^-	NH_4^+	P-total	TSS	*E.coli*
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	cfu/100ml
Unie-Influent-24-1-2011	2011-001687	135	275	7.5	<0.05	<0.01	2.9	5.1	45	1790000
Unie-Influent-25-1-2011	2011-001703	97	220	7.4	<0.05	<0.01	3.0	6.1	61	1387500
Unie-Influent-26-1-2011	2011-001834	110	235	6.8	<0.05	<0.01	2.6	5.6	36	1790000
Unie-Influent-31-1-2011	2011-001902	140	275	10.2	<0.05	<0.01	4.1	5.6	41	2080000
Unie-Influent-2-2-2011	2011-002474	125	245	8.4	0.80	<0.01	3.5	5.3	44	3180000
Unie-Influent-3-2-2011	2011-002540	130	285	8.2	<0.05	<0.01	3.5	5.7	49	2490000
	n:	6	6	6	6	6	6	6	6	6
	Mean:	123	256	8.1	<0.18	<0.01	3.3	5.6	46	2119583
	STD:	16	26	1.2	0.31	0.00	0.5	0.3	9	635052
	Min:	97	220	6.8	<0.05	<0.01	2.6	5.1	36	1387500
	Max:	140	285	10.2	0.80	<0.01	4.1	6.1	61	3180000

Table 39. Characteristics of effluent at *Unie*

Composite Sample Label	Laboratory Code	BOD_5	COD	TKN	NO_3^-	NO_2^-	NH_4^+	P-total	TSS	*E.coli*
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	cfu/100ml
Unie-Effluent-25-1-2011	2011-001704	2.4	27	1.3	0.11	<0.01	0.68	1.0	34	1114
Unie-Effluent-26-1-2011	2011-001835	2.2	24	1.3	<0.05	<0.01	0.81	1.0	28	872
Unie-Effluent-27-1-2011	2011-001875	1.6	22	1.3	<0.05	<0.01	0.87	1.0	29	981
Unie-Effluent-2-2-2011	2011-002475	2.4	24	1.4	<0.05	<0.01	0.90	1.2	31	950
Unie-Effluent-3-2-2011	2011-002541	1.4	25	1.4	<0.05	<0.01	0.86	1.2	32	635
Unie-Effluent-4-2-2011	2011-002548	1.6	20	1.4	0.07	<0.01	0.87	1.2	30	690
	n:	6	6	6	6	6	6	6	6	6
	Mean:	1.9	24	1.4	<0.06	<0.01	0.83	1.1	31	874
	STD:	0.5	2	0.1	0.02	0.00	0.08	0.1	2	182
	Min:	1.4	20	1.3	<0.05	<0.01	0.68	1.0	28	635
	Max:	2.4	27	1.4	0.11	<0.01	0.90	1.2	34	1114

Appendix 11. Summary and Graphical Representation of Measured O_2, pH and Temperature Values in Influent and Effluent at *Station*

Table 40. Statistical representation of measured O_2 (mg/l) values in influent at *Station*

	n	Mean	Std. Deviation	Minimum	Maximum
		mg/l	mg/l	mg/l	mg/l
Station-Influent-24-1-2011	12	1.2	0.7	0.6	2.5
Station-Influent-25-1-2011	6	2.0	0.9	1.3	3.6
Station-Influent-26-1-2011	7	1.8	0.7	0.9	2.8
Station-Influent-31-1-2011	7	1.9	0.5	1.1	2.5
Station-Influent-2-2-2011	7	1.6	0.5	1.0	2.5
Station-Influent-3-2-2011	7	1.3	0.4	0.7	1.9
Week 4	25	1.5	0.8	0.6	3.6
Week 5	21	1.6	0.5	0.7	2.5
Total	46	1.6	0.7	0.6	3.6

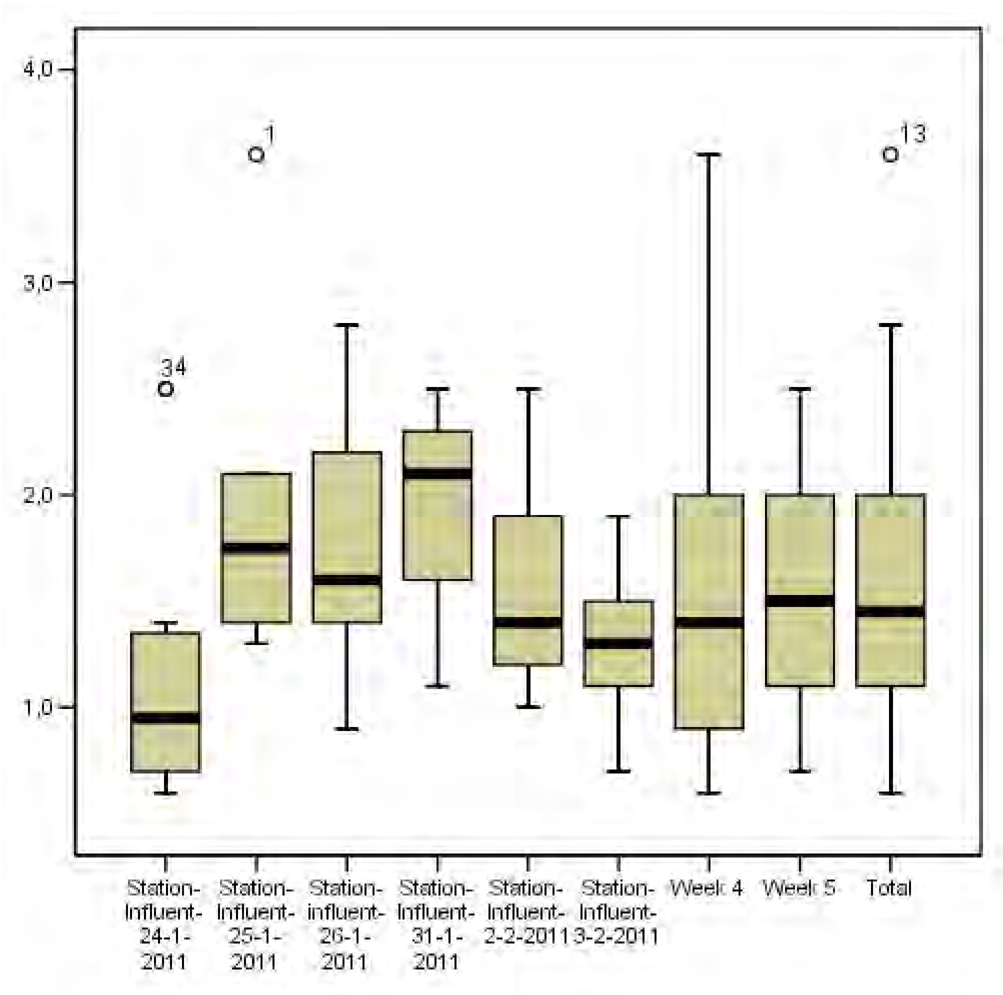

Figure 23. Box plot of measured O_2 (mg/l) values in influent at *Station*

Table 41. Statistical representation of measured O_2 (mg/l) values in effluent at *Station*

	n	Mean	Std. Deviation	Minimum	Maximum
		mg/l	mg/l	mg/l	mg/l
Station-Effluent-25-1-2011	6	1.5	0.2	1.2	1.7
Station-Effluent-26-1-2011	7	1.5	0.2	1.2	1.6
Station-Effluent-27-1-2011	11	0.9	0.1	0.8	1.1
Station-Effluent-2-2-2011	7	1.9	0.1	1.8	2.1
Station-Effluent-3-2-2011	7	1.8	0.3	1.5	2.3
Station-Effluent-4-2-2011	8	1.2	0.1	0.9	1.3
Week 4	24	1.2	0.3	0.8	1.7
Week 5	22	1.6	0.4	0.9	2.3
Total	46	1.4	0.4	0.8	2.3

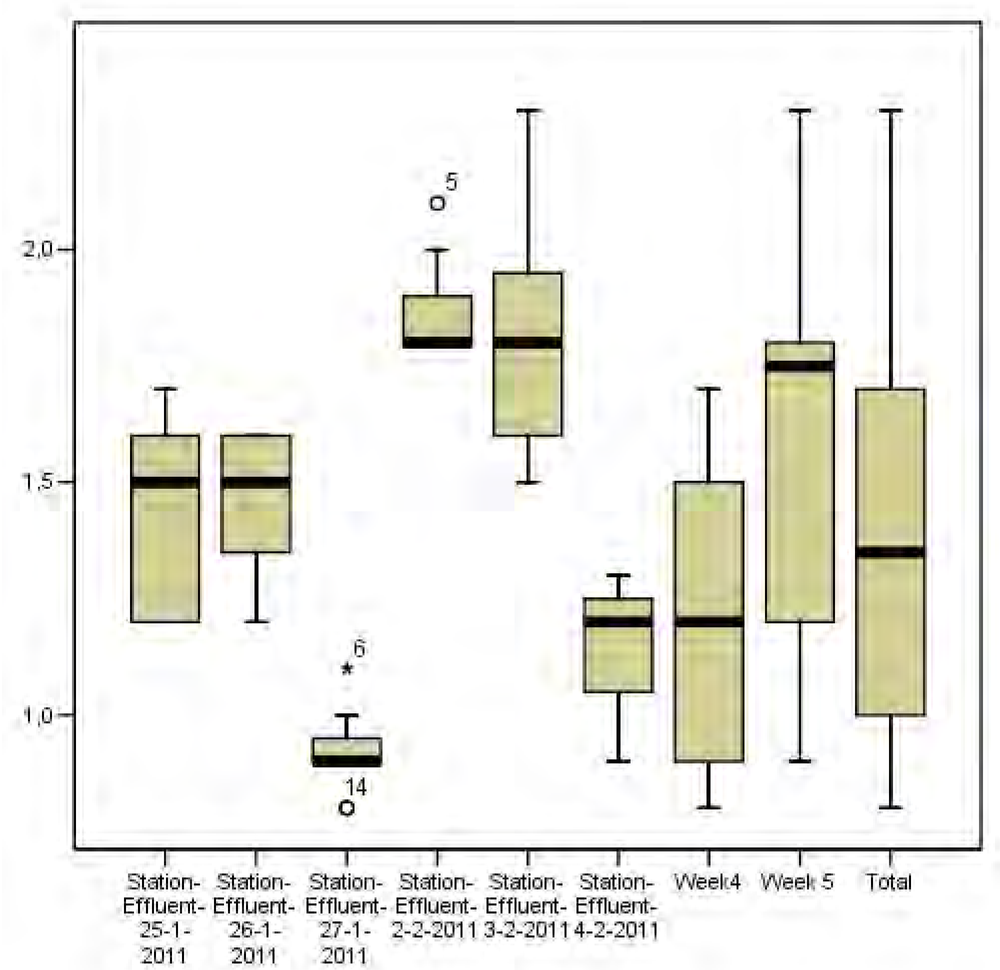

Figure 24. Box plot of measured O_2 (mg/l) values in effluent at *Station*

Table 42. Statistical representation of measured pH (-) values in influent at *Station*

	n	Mean	Std. Deviation	Minimum	Maximum
		-	-	-	-
Station-Influent-24-1-2011	12	7.11	0.05	7.02	7.20
Station-Influent-25-1-2011	6	6.97	0.12	6.84	7.16
Station-Influent-26-1-2011	7	7.17	0.06	7.10	7.28
Station-Influent-31-1-2011	7	7.18	0.02	7.15	7.19
Station-Influent-2-2-2011	7	7.17	0.05	7.10	7.26
Station-Influent-3-2-2011	7	7.16	0.05	7.07	7.22
Week 4	25	7.09	0.10	6.84	7.28
Week 5	21	7.17	0.04	7.07	7.26
Total	46	7.13	0.09	6.84	7.28

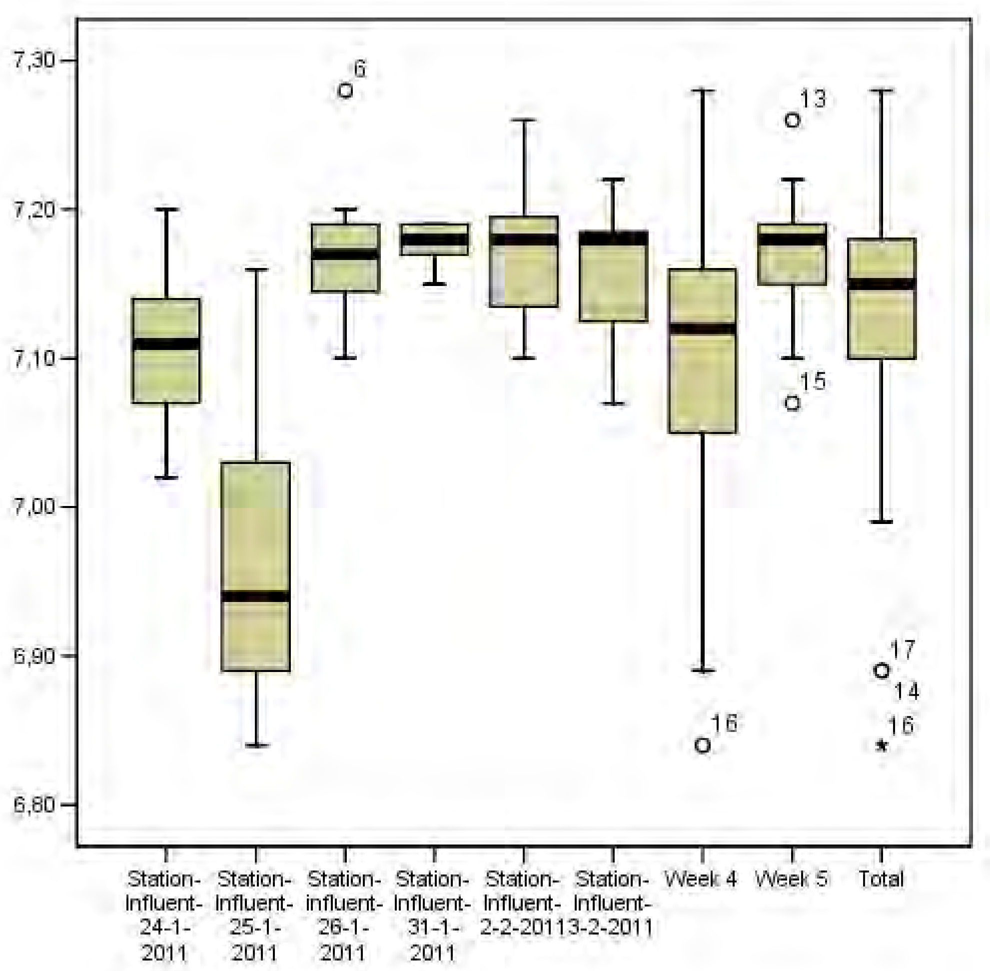

Figure 25. Box plot of measured pH (-) values in influent at *Station*

Table 43. Statistical representation of measured pH (-) values in effluent at *Station*

	n	Mean	Std. Deviation	Minimum	Maximum
		-	-	-	-
Station-Effluent-25-1-2011	6	6.84	0.12	6.65	7.00
Station-Effluent-26-1-2011	7	7.00	0.01	6.98	7.02
Station-Effluent-27-1-2011	11	7.04	0.07	6.86	7.13
Station-Effluent-2-2-2011	7	7.09	0.03	7.07	7.13
Station-Effluent-3-2-2011	7	7.09	0.03	7.05	7.12
Station-Effluent-4-2-2011	8	7.04	0.03	7.00	7.08
Week 4	24	6.98	0.11	6.65	7.13
Week 5	22	7.07	0.04	7.00	7.13
Total	46	7.02	0.10	6.65	7.13

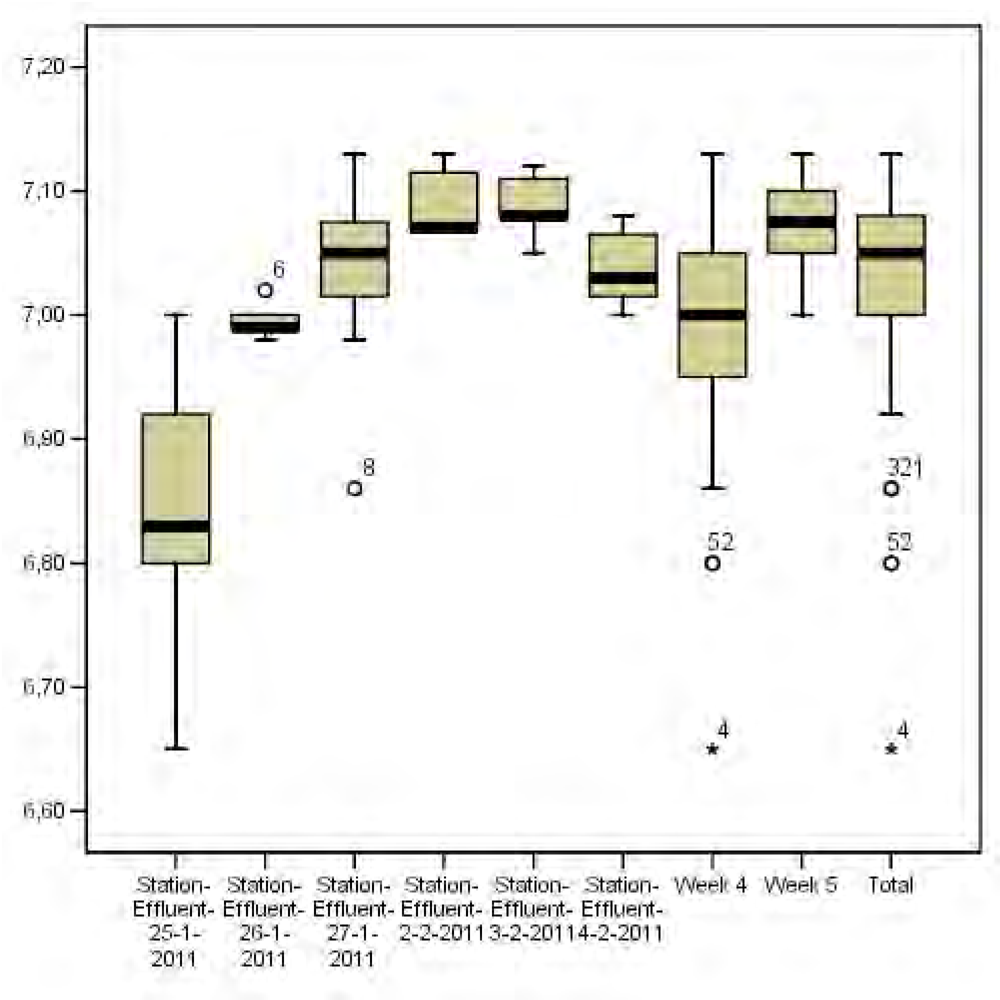

Figure 26. Box plot of measured pH (-) values in effluent at *Station*

Table 44. Statistical representation of measured temperature (°C) values in influent at *Station*

	n	Mean	Std. Deviation	Minimum	Maximum
		°C	°C	°C	°C
Station-Influent-24-1-2011	12	9.2	0.2	8.9	9.5
Station-Influent-25-1-2011	6	9.0	0.4	8.4	9.3
Station-Influent-26-1-2011	7	8.9	0.3	8.5	9.3
Station-Influent-31-1-2011	7	8.2	0.1	8.1	8.5
Station-Influent-2-2-2011	7	8.2	0.2	8.0	8.5
Station-Influent-3-2-2011	7	8.5	0.2	8.2	8.7
Week 4	25	9.0	0.3	8.4	9.5
Week 5	21	8.3	0.2	8.0	8.7
Total	46	8.7	0.5	8.0	9.5

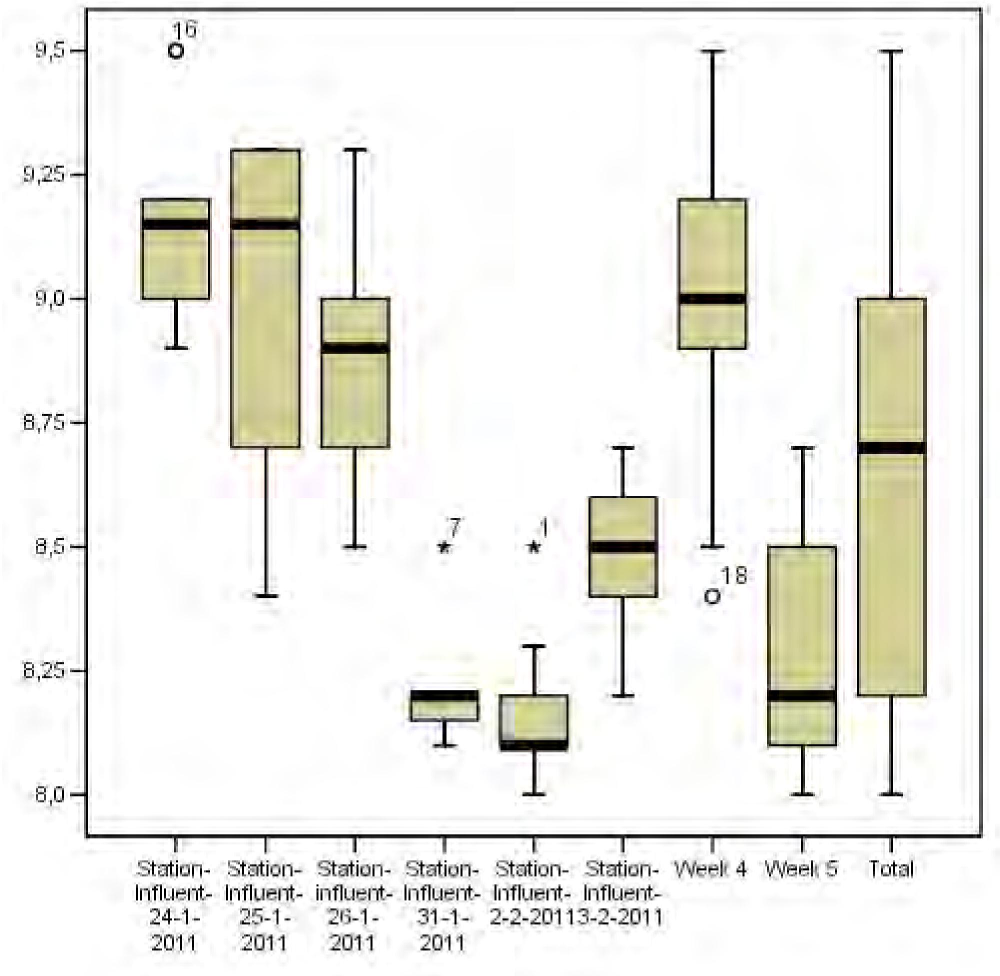

Figure 27. Box plot of measured temperature (°C) values in influent at *Station*

Table 45. Statistical representation of measured temperature (°C) values in effluent at *Station*

	n	Mean	Std. Deviation	Minimum	Maximum
		°C	°C	°C	°C
Station-Effluent-25-1-2011	6	6.3	0.2	6.0	6.5
Station-Effluent-26-1-2011	7	6.0	0.3	5.6	6.4
Station-Effluent-27-1-2011	11	5.5	0.3	5.2	5.9
Station-Effluent-2-2-2011	7	5.0	0.1	4.9	5.2
Station-Effluent-3-2-2011	7	5.7	0.4	5.3	6.4
Station-Effluent-4-2-2011	8	5.6	0.4	5.4	6.5
Week 4	24	5.8	0.4	5.2	6.5
Week 5	22	5.4	0.4	4.9	6.5
Total	46	5.7	0.5	4.9	6.5

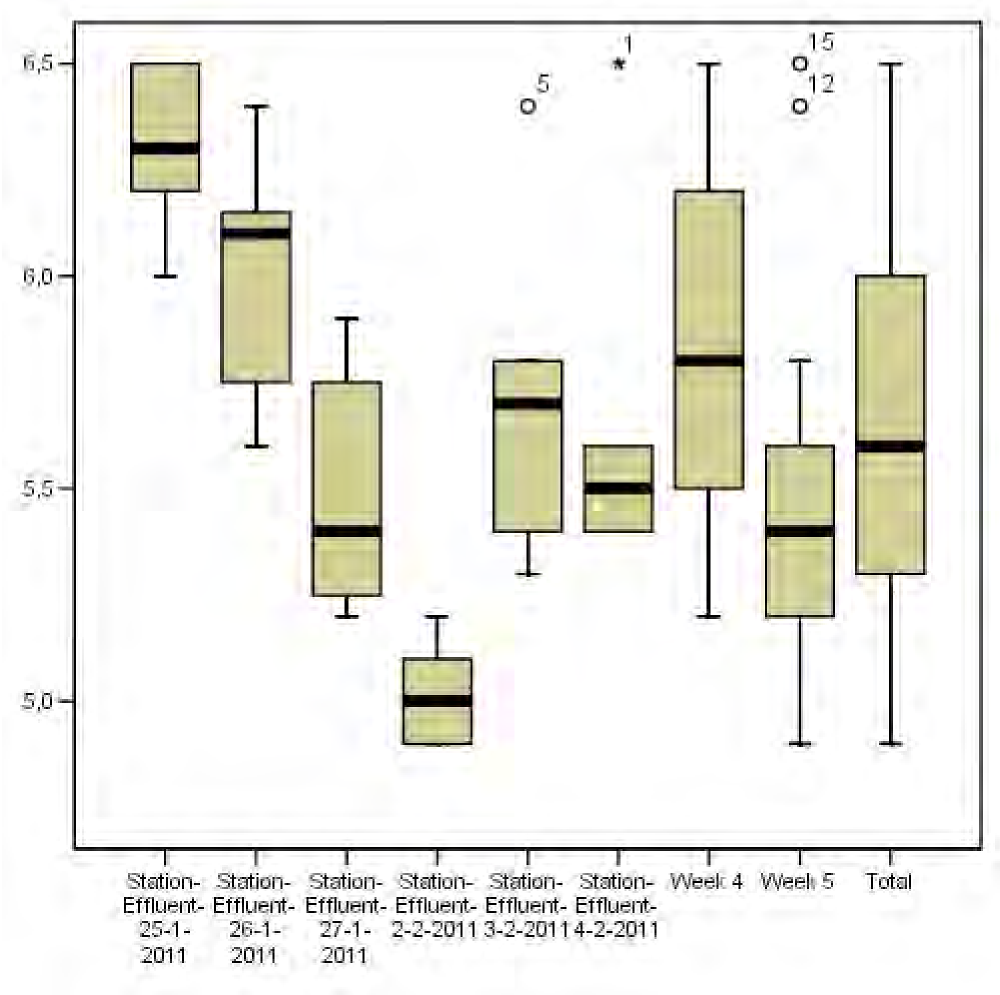

Figure 28. Box plot of measured temperature (°C) values in effluent at *Station*

Appendix 12. Measured O_2, Temperature and pH Values in Influent and Effluent at *Station*

Table 46. Measured O_2, Temperature and pH values in influent at *Station* on 24-1-2011

	Composite Sample Label:	Station-Influent-24-1-2011
Location: Station (T1)	**Type:** Influent	**Date:** 24-1-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T1-I-1	8:07	0.7	6	9.5	7.05	Collection tank empty, no inflow
T1-I-2	9:00	1.1	10	9.0	7.09	Collection tank empty, no inflow
T1-I-3	10:00	2.5	21	9.1	7.08	Collection tank low, inflow
T1-I-4	---	---	---	---	---	Stuck with car
T1-I-5	12:00	2.5	20	9.0	7.12	Collection tank low, inflow
T1-I-6	13:06	1.3	11	9.2	7.20	Collection tank low, no inflow
T1-I-7	14:00	1.4	12	9.5	7.12	Collection tank low, no inflow
T1-I-8	15:00	0.7	6	9.2	7.02	Collection tank low, no inflow
T1-I-9	16:06	0.8	7	9.2	7.17	Collection tank low, no inflow
T1-I-10	17:00	0.7	6	8.9	7.10	Collection tank low, no inflow
T1-I-11	18:00	0.6	5	9.2	7.06	Collection tank half, inflow
T1-I-12	19:00	0.7	6	9.0	7.12	Collection tank half, no inflow
T1-I-13	20:00	1.3	11	9.0	7.16	Collection tank empty, no inflow

	***n*:**	12	12	12	12
	Mean:	1.2	10.1	9.2	7.11
	STD:	0.7	5.4	0.2	0.05
	Min:	0.6	5.0	8.9	7.02
	Max:	2.5	21.0	9.5	7.20

Table 47. Measured O_2, Temperature and pH values in effluent at *Station* on 25-1-2011

	Composite Sample Label:	Station-Effluent-25-1-2011
Location: Station (T1)	**Type:** Effluent	**Date:** 25-1-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T1-E-1	9:35	1.2	9	6.3	6.92	Oil on water
T1-E-2	11:25	1.5	11	6.5	6.80	---
T1-E-3	13:20	1.7	14	6.3	6.86	---
T1-E-4	14:50	1.2	9	6.5	6.65	Less oil on water
T1-E-5	16:23	1.6	13	6.2	6.80	---
T1-E-6	17:50	1.5	12	6.0	7.00	---

	***n*:**	6	6	6	6
	Mean:	1.5	11.3	6.3	6.84
	STD:	0.2	2.1	0.2	0.12
	Min:	1.2	9.0	6.0	6.65
	Max:	1.7	14.0	6.5	7.00

Table 48. Measured O_2, Temperature and pH values in influent at *Station* on 25-1-2011

	Composite Sample Label:	Station-Influent-25-1-2011
Location: Station (T1)	**Type:** Influent	**Date:** 25-1-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T1-I-1	9:25	3.6	31	9.3	6.99	Collection tank empty, no inflow; Oxygen meter checked at zero
T1-I-2	11:15	2.1	18	9.3	6.89	Collection tank low, little inflow
T1-I-3	13:12	1.5	14	9.3	7.03	Collection tank empty, inflow
T1-I-4	14:40	1.4	12	9.0	6.84	Pumping (Water visible on HF)
T1-I-5	16:05	1.3	11	8.7	6.89	Collection tank empty, no inflow
T1-I-6	17:35	2.0	16	8.4	7.16	Collection tank low, no inflow
	19:10					Collection tank low, no inflow
	***n*:**	6	6	6	6	
	Mean:	2.0	17.0	9.0	6.97	
	STD:	0.9	7.3	0.4	0.12	
	Min:	1.3	11.0	8.4	6.84	
	Max:	3.6	31.0	9.3	7.16	

Table 49. Measured O_2, Temperature and pH values in effluent at *Station* on 26-1-2011

	Composite Sample Label:	Station-Effluent-26-1-2011
Location: Station (T1)	**Type:** Effluent	**Date:** 26-1-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T1-E-1	9:25	1.6	13	5.8	6.99	Oil on water
T1-E-2	10:50	1.6	13	6.1	6.98	---
T1-E-3	12:20	1.6	13	6.1	7.00	Composite bottle shaken as it nearly fell before analysis
T1-E-4	13:45	1.2	10	6.4	6.99	---
T1-E-5	15:15	1.5	12	6.2	6.99	Higher TSS in sample due to SS being collected in sample due to water disturbance (bio film on pump)
T1-E-6	16:50	1.4	11	5.6	7.02	---
T1-E-7	18:20	1.3	11	5.7	7.00	Less oil on water
	***n*:**	7	7	7	7	
	Mean:	1.5	11.9	6.0	7.00	
	STD:	0.2	1.2	0.3	0.01	
	Min:	1.2	10.0	5.6	6.98	
	Max:	1.6	13.0	6.4	7.02	

Table 50. Measured O_2, Temperature and pH values in influent at *Station* on 26-1-2011

	Composite Sample Label:	Station-Influent-26-1-2011
Location: Station (T1)	**Type:** Influent	**Date:** 26-1-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T1-I-1	9:10	1.8	15	8.5	7.10	Collection tank at top of pump, inflow
T1-I-2	10:40	2.8	24	9.0	7.14	Collection tank empty, inflow
T1-I-3	12:10	2.6	22	8.9	7.15	Collection tank low, no inflow
T1-I-4	13:31	1.6	14	9.3	7.18	Collection tank low, no inflow
T1-I-5	15:02	1.5	13	9.0	7.20	Collection tank low, no inflow
T1-I-6	16:30	1.3	11	8.8	7.28	Collection tank low, no inflow; small bits of frozen water in sample container (rinsed out)
T1-I-7	18:10	0.9	7	8.6	7.17	Collection tank low, no inflow
	***n*:**	7	7	7	7	
	Mean:	1.8	15.1	8.9	7.17	
	STD:	0.7	6.0	0.3	0.06	
	Min:	0.9	7.0	8.5	7.10	
	Max:	2.8	24.0	9.3	7.28	

Table 51. Measured O_2, Temperature and pH values in effluent at *Station* on 27-1-2011

	Composite Sample Label:	Station-Effluent-27-1-2011
Location: Station (T1)	**Type:** Effluent	**Date:** 27-1-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T1-E-1	9:20	0.8	6	5.8	7.05	Collection tank empty, no inflow
T1-E-2	10:07	0.9	7	5.2	6.98	---
T1-E-3	10:58	1.0	8	5.3	7.12	---
T1-E-4	12:00	0.8	6	5.9	7.02	---
T1-E-5	13:00	1.0	7	5.8	7.07	---
T1-E-6	13:55	1.1	8	5.6	7.13	---
T1-E-7	14:45	0.9	7	5.4	7.01	Collection tank low, inflow
T1-E-8	15:55	0.9	7	5.2	6.86	---
T1-E-9	17:00	0.9	7	5.7	7.08	---
T1-E-10	17:47	0.9	7	5.3	7.06	---
T1-E-11	18:45	0.9	7	5.2	7.05	---
	***n*:**	11	11	11	11	
	Mean:	0.9	7.0	5.5	7.04	
	STD:	0.1	0.6	0.3	0.07	
	Min:	0.8	6.0	5.2	6.86	
	Max:	1.1	8.0	5.9	7.13	

Table 52. Measured O_2, Temperature and pH values in influent at *Station* on 31-1-2011

	Composite Sample Label:	Station-Influent-31-1-2011
Location: Station (T1)	**Type:** Influent	**Date:** 31-1-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T1-I-1	8:30	1.5	12	8.1	7.15	Collection tank empty, inflow
T1-I-2	9:13	2.1	17	8.2	7.18	Collection tank low, no inflow
T1-I-3	10:05	2.5	21	8.2	7.19	Collection tank low, no inflow
T1-I-4	11:00	2.5	21	8.2	7.19	Collection tank low, no inflow
T1-I-5	12:15	2.1	17	8.1	7.16	Collection tank low, no inflow
T1-I-6	13:00	1.7	14	8.2	7.18	Collection tank low, no inflow
T1-I-7	14:25	1.1	9	8.5	7.19	Collection tank low, no inflow; Sick
	***n*:**	7	7	7	7	
	Mean:	1.9	15.9	8.2	7.18	
	STD:	0.5	4.5	0.1	0.02	
	Min:	1.1	9.0	8.1	7.15	
	Max:	2.5	21.0	8.5	7.19	

Table 53. Measured O_2, Temperature and pH values in effluent at *Station* on 2-2-2011

	Composite Sample Label:	Station-Effluent-2-2-2011
Location: Station (T1)	**Type:** Effluent	**Date:** 2-2-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T1-E-1	9:20	1.8	14	4.9	7.07	Oil on water
T1-E-2	10:45	1.8	14	5.0	7.07	---
T1-E-3	12:20	1.8	14	5.2	7.10	Ice on southern HF bed
T1-E-4	13:50	2.0	15	4.9	7.07	---
T1-E-5	15:15	2.1	17	4.9	7.07	---
T1-E-6	16:35	1.8	14	5.0	7.13	---
T1-E-7	18:08	1.8	14	5.2	7.13	---
	***n*:**	7	7	7	7	
	Mean:	1.9	14.6	5.0	7.09	
	STD:	0.1	1.1	0.1	0.03	
	Min:	1.8	14.0	4.9	7.07	
	Max:	2.1	17.0	5.2	7.13	

Table 54. Measured O_2, Temperature and pH values in influent at *Station* on 2-2-2011

	Composite Sample Label:	Station-Influent-2-2-2011
Location: Station (T1)	**Type:** Influent	**Date:** 2-2-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T1-I-1	9:05	1.4	12	8.5	7.10	Collection tank empty, no inflow
T1-I-2	10:31	2.5	21	8.1	7.12	Collection tank low, little inflow
T1-I-3	12:05	2.0	17	8.1	7.18	Collection tank low, no inflow
T1-I-4	13:33	1.8	15	8.1	7.20	Collection tank low, no inflow
T1-I-5	15:00	1.3	11	8.0	7.19	Collection tank low, no inflow
T1-I-6	16:20	1.0	8	8.1	7.26	Collection tank low, no inflow
T1-I-7	17:54	1.1	9	8.3	7.15	Collection tank low, inflow
	***n*:**	7	7	7	7	
	Mean:	1.6	13.3	8.2	7.17	
	STD:	0.5	4.6	0.2	0.05	
	Min:	1.0	8.0	8.0	7.10	
	Max:	2.5	21.0	8.5	7.26	

Table 55. Measured O_2, Temperature and pH values in effluent at *Station* on 3-2-2011

	Composite Sample Label:	Station-Effluent-3-2-2011
Location: Station (T1)	**Type:** Effluent	**Date:** 3-2-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T1-E-1	9:20	1.8	15	5.3	7.05	---
T1-E-2	10:45	1.8	14	5.7	7.08	---
T1-E-3	12:10	2.3	18	5.8	7.08	---
T1-E-4	13:50	2.1	17	5.8	7.08	---
T1-E-5	15:20	1.5	12	6.4	7.12	---
T1-E-6	16:33	1.5	12	5.4	7.10	---
T1-E-7	18:03	1.7	13	5.4	7.12	---
	***n*:**	7	7	7	7	
	Mean:	1.8	14.4	5.7	7.09	
	STD:	0.3	2.4	0.4	0.03	
	Min:	1.5	12.0	5.3	7.05	
	Max:	2.3	18.0	6.4	7.12	

Table 56. Measured O_2, Temperature and pH values in influent at *Station* on 3-2-2011

		Composite Sample Label:			Station-Influent-3-2-2011	
Location: Station (T1)		**Type:** Influent			**Date:** 3-2-2011	

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T1-I-1	9:10	1.5	13	8.5	7.07	Collection tank low, no inflow
T1-I-2	10:30	1.1	9	8.3	7.15	Collection tank low, no inflow
T1-I-3	12:00	0.7	6	8.5	7.10	Collection tank low (above pump), no inflow
T1-I-4	13:31	1.1	9	8.7	7.18	Collection tank empty, no inflow
T1-I-5	15:05	1.9	16	8.7	7.18	Collection tank empty, no inflow
T1-I-6	16:21	1.3	11	8.5	7.19	Collection tank empty, no inflow
T1-I-7	17:50	1.5	12	8.2	7.22	Collection tank empty, no inflow
	***n*:**	7	7	7	7	
	Mean:	1.3	10.9	8.5	7.16	
	STD:	0.4	3.2	0.2	0.05	
	Min:	0.7	6.0	8.2	7.07	
	Max:	1.9	16.0	8.7	7.22	

Table 57. Measured O_2, Temperature and pH values in effluent at *Station* on 4-2-2011

		Composite Sample Label:			Station-Effluent-4-2-2011	
Location: Station (T1)		**Type:** Effluent			**Date:** 4-2-2011	

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T1-E-1	8:45	0.9	7	6.5	7.00	---
T1-E-2	9:39	1.1	9	5.4	7.08	---
T1-E-3	10:20	1.2	10	5.4	7.08	---
T1-E-4	10:56	1.0	8	5.4	7.05	---
T1-E-5	11:36	1.2	9	5.5	7.02	---
T1-E-6	12:15	1.2	10	5.6	7.01	---
T1-E-7	12:50	1.3	10	5.6	7.02	---
T1-E-8	13:28	1.3	10	5.5	7.04	---
	***n*:**	8	8	8	8	
	Mean:	1.2	9.1	5.6	7.04	
	STD:	0.1	1.1	0.4	0.03	
	Min:	0.9	7.0	5.4	7.00	
	Max:	1.3	10.0	6.5	7.08	

Appendix 13. Summary and Graphical Representation of Measured O_2, pH and Temperature Values in Influent and Effluent at *School*

Table 58. Statistical representation of measured O_2 (mg/l) values in influent at *School*

	n	Mean	Std. Deviation	Minimum	Maximum
		mg/l	mg/l	mg/l	mg/l
School-Influent-24-1-2011	12	0.5	0.2	0.3	0.9
School-Influent-25-1-2011	6	1.0	0.1	0.8	1.1
School-Influent-26-1-2011	7	1.0	0.4	0.6	1.8
School-Influent-31-1-2011	7	0.7	0.1	0.6	1.0
School-Influent-2-2-2011	7	1.2	0.6	0.7	2.2
School-Influent-3-2-2011	7	1.1	0.5	0.6	2.0
Week 4	25	0.8	0.4	0.3	1.8
Week 5	21	1.0	0.5	0.6	2.2
Total	46	0.9	0.4	0.3	2.2

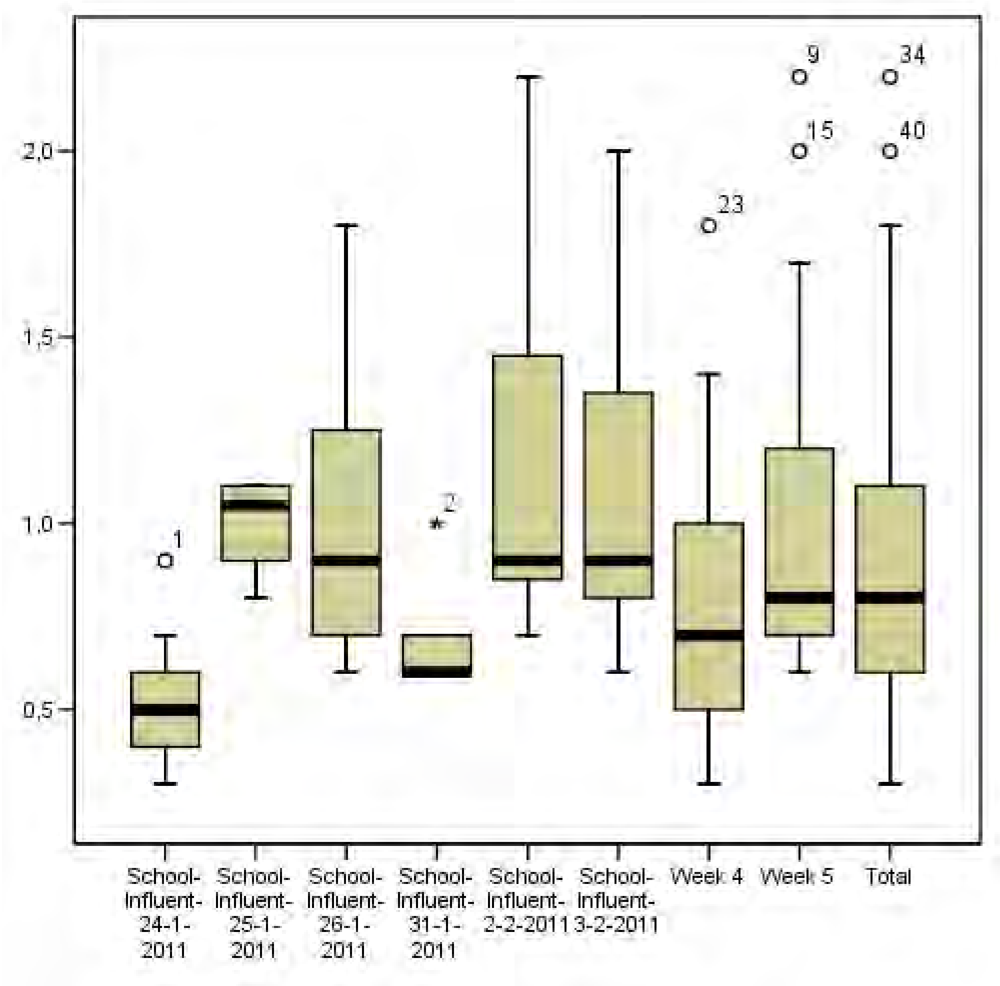

Figure 29. Box plot of measured O_2 (mg/l) values in influent at *School*

Table 59. Statistical representation of measured O_2 (mg/l) values in effluent at *School*

	n	Mean	Std. Deviation	Minimum	Maximum
		mg/l	mg/l	mg/l	mg/l
School-Effluent-25-1-2011	6	5.6	0.2	5.3	5.8
School-Effluent-26-1-2011	7	4.7	0.9	3.5	5.6
School-Effluent-27-1-2011	11	5.0	1.0	3.5	6.5
School-Effluent-2-2-2011	7	6.1	1.0	4.9	7.4
School-Effluent-3-2-2011	7	6.1	0.8	4.8	7.1
School-Effluent-4-2-2011	8	6.5	0.2	6.0	6.8
Week 4	24	5.1	0.9	3.5	6.5
Week 5	22	6.2	0.7	4.8	7.4
Total	46	5.6	1.0	3.5	7.4

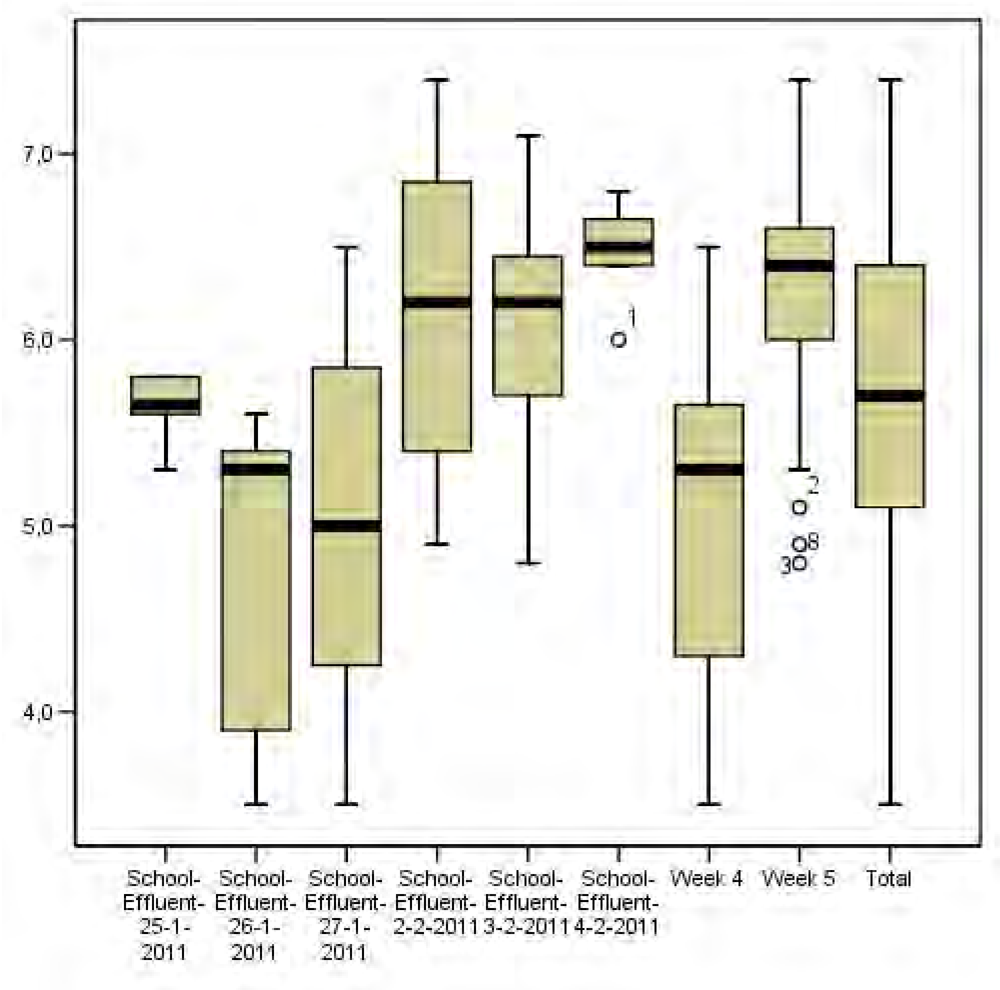

Figure 30. Box plot of measured O_2 (mg/l) values in effluent at *School*

Table 60. Statistical representation of measured pH (-) values in influent at *School*

	n	Mean	Std. Deviation	Minimum	Maximum
		-	-	-	-
School-Influent-24-1-2011	12	7.07	0.05	7.00	7.16
School-Influent-25-1-2011	6	6.98	0.09	6.87	7.12
School-Influent-26-1-2011	7	7.10	0.06	7.01	7.17
School-Influent-31-1-2011	7	7.17	0.03	7.14	7.21
School-Influent-2-2-2011	7	7.35	0.14	7.15	7.52
School-Influent-3-2-2011	7	7.29	0.04	7.20	7.33
Week 4	25	7.06	0.08	6.87	7.17
Week 5	21	7.27	0.11	7.14	7.52
Total	46	7.15	0.14	6.87	7.52

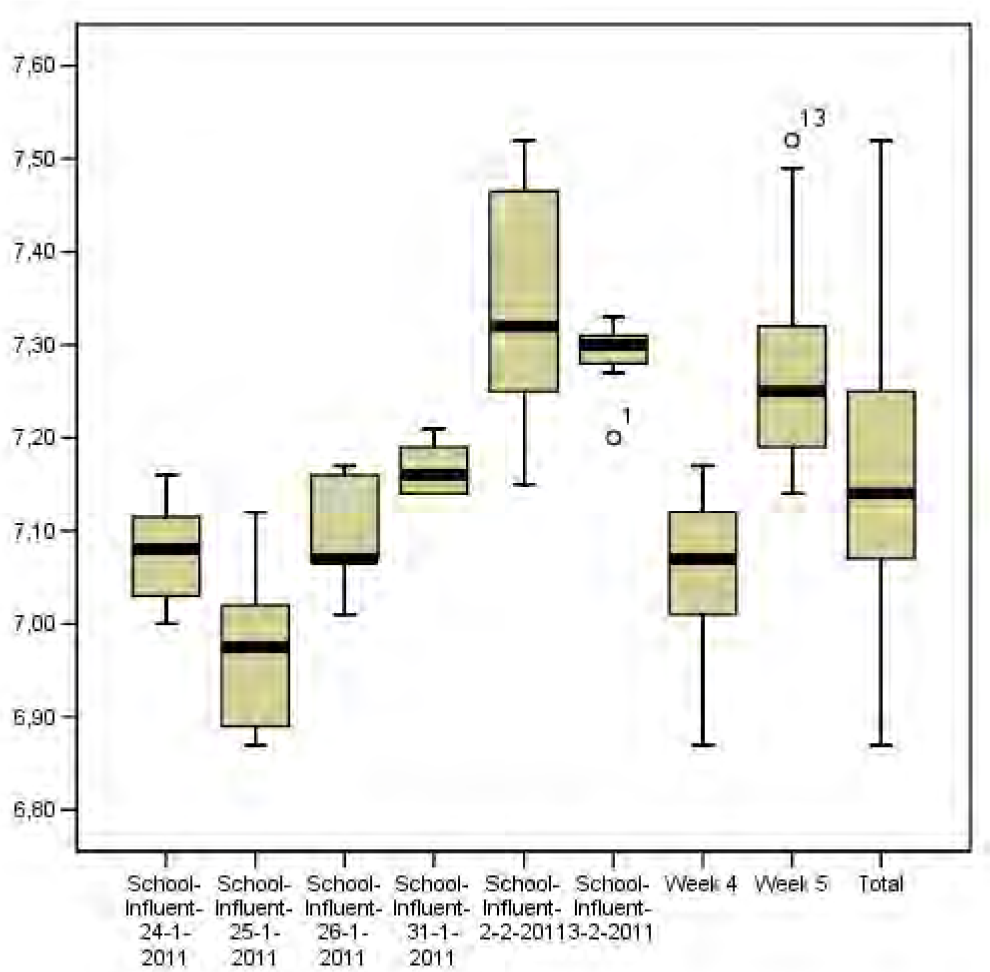

Figure 31. Box plot of measured pH (-) values in influent at *School*

Table 61. Statistical representation of measured pH (-) values in effluent at *School*

	n	Mean	Std. Deviation	Minimum	Maximum
		-	-	-	-
School-Effluent-25-1-2011	6	6.77	0.08	6.66	6.88
School-Effluent-26-1-2011	7	6.86	0.05	6.81	6.92
School-Effluent-27-1-2011	11	6.87	0.06	6.79	6.97
School-Effluent-2-2-2011	7	7.03	0.06	6.97	7.12
School-Effluent-3-2-2011	7	7.04	0.04	7.00	7.10
School-Effluent-4-2-2011	8	6.98	0.01	6.96	6.99
Week 4	24	6.84	0.07	6.66	6.97
Week 5	22	7.02	0.05	6.96	7.12
Total	46	6.93	0.11	6.66	7.12

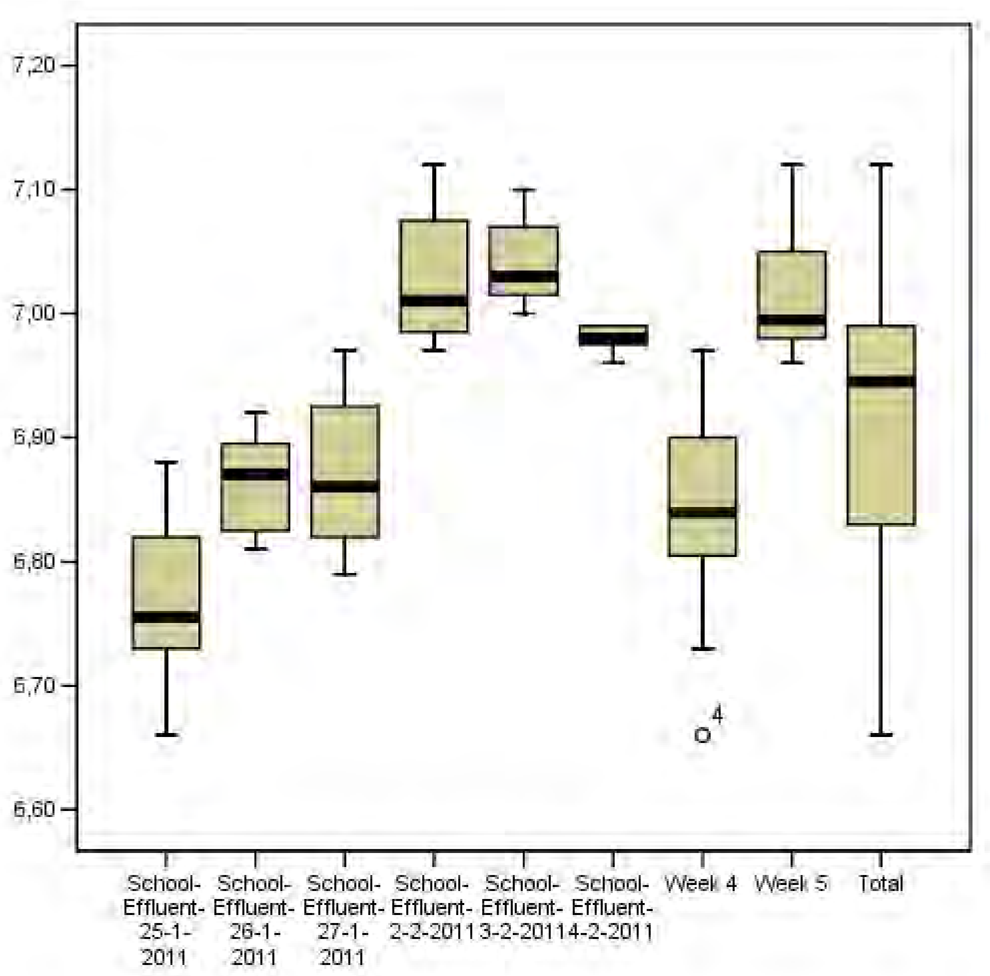

Figure 32. Box plot of measured pH (-) values in effluent at *School*

Table 62. Statistical representation of measured temperature (°C) values in influent at *School*

	n	Mean	Std. Deviation	Minimum	Maximum
		°C	°C	°C	°C
School-Influent-24-1-2011	12	11.9	0.3	11.3	12.3
School-Influent-25-1-2011	6	11.3	0.6	10.4	11.8
School-Influent-26-1-2011	7	10.8	0.4	10.1	11.1
School-Influent-31-1-2011	7	10.7	0.3	10.1	11.0
School-Influent-2-2-2011	7	10.5	0.1	10.3	10.7
School-Influent-3-2-2011	7	11.4	0.3	10.8	11.7
Week 4	25	11.4	0.6	10.1	12.3
Week 5	21	10.9	0.5	10.1	11.7
Total	46	11.2	0.6	10.1	12.3

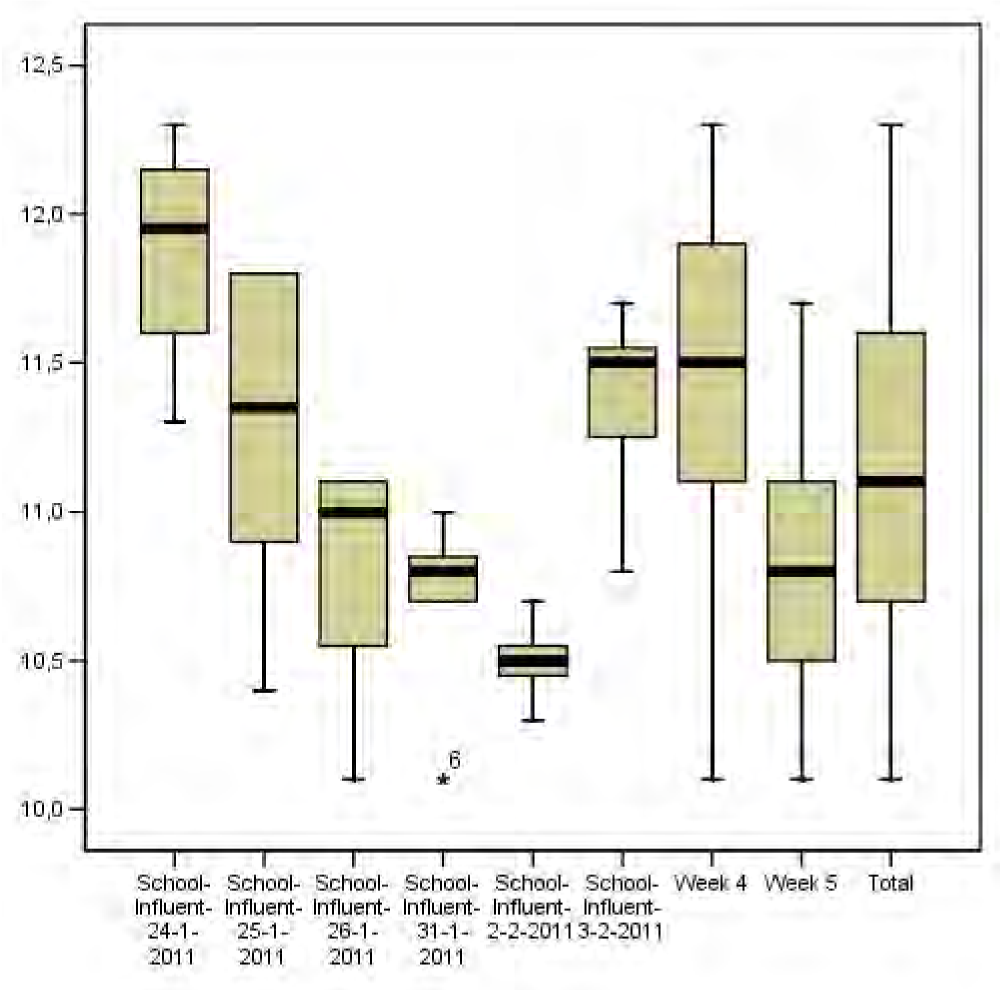

Figure 33. Box plot of measured temperature (°C) values in influent at *School*

Table 63. Statistical representation of measured temperature (°C) values in effluent at *School*

	n	Mean	Std. Deviation	Minimum	Maximum
		°C	°C	°C	°C
School-Effluent-25-1-2011	6	7.5	0.3	7.0	7.9
School-Effluent-26-1-2011	7	7.1	0.2	6.9	7.4
School-Effluent-27-1-2011	11	6.5	0.3	6.0	7.0
School-Effluent-2-2-2011	7	5.2	0.1	5.0	5.4
School-Effluent-3-2-2011	7	6.1	0.3	5.6	6.4
School-Effluent-4-2-2011	8	6.4	0.1	6.2	6.5
Week 4	24	6.9	0.5	6.0	7.9
Week 5	22	5.9	0.5	5.0	6.5
Total	46	6.4	0.7	5.0	7.9

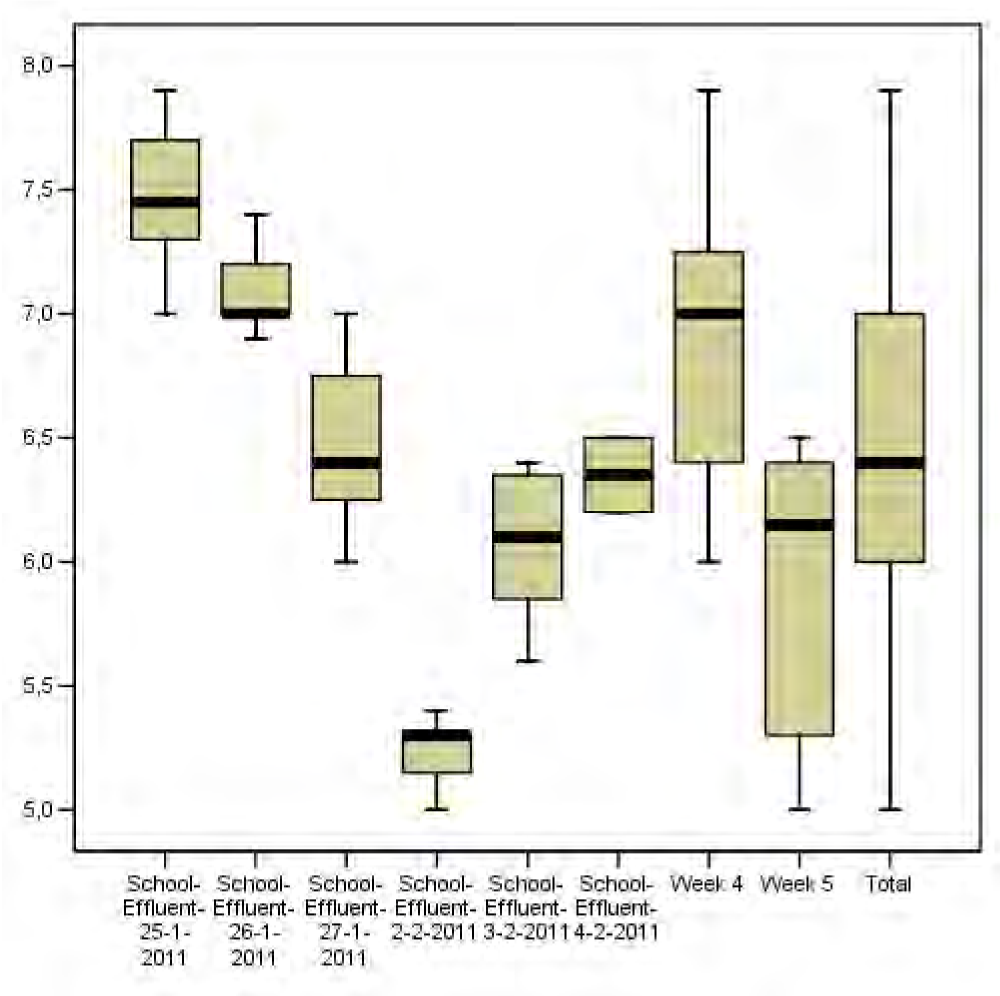

Figure 34. Box plot of measured temperature (°C) values in effluent at *School*

Appendix 14. Measured O_2, Temperature and pH Values in Influent and Effluent at *School*

Table 64. Measured O_2, Temperature and pH values in influent at *School* on 24-1-2011

	Composite Sample Label:	School-Influent-24-1-2011
Location: School (T2)	**Type:** Influent	**Date:** 24-1-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T2-I-1	8:25	0.9	8	12.3	7.00	Collection tank empty, inflow
T2-I-2	9:14	0.7	5	12.0	7.04	Collection tank low, inflow
T2-I-3	10:13	0.6	5	12.0	7.02	Collection tank low, inflow
T2-I-4	---	---	---	---	---	Stuck with car
T2-I-5	12:15	0.6	5	12.0	7.07	Collection tank low, inflow
T2-I-6	13:20	0.3	3	12.3	7.09	Collection tank low, inflow
T2-I-7	14:14	0.5	4	12.3	7.05	Collection tank low, little inflow
T2-I-8	15:14	0.5	4	11.9	7.09	Collection tank low, no inflow
T2-I-9	16:17	0.5	4	11.9	7.12	Collection tank low, little inflow
T2-I-10	17:09	0.4	3	11.4	7.12	Collection tank half, little inflow
T2-I-11	18:12	0.6	5	11.6	7.16	Collection tank half, no inflow
T2-I-12	19:14	0.4	4	11.6	7.00	Collection tank half, no inflow
T2-I-13	20:30	0.3	3	11.3	7.11	Collection tank half, no inflow
	***n*:**	12	12	12	12	
	Mean:	0.5	4.4	11.9	7.07	
	STD:	0.2	1.4	0.3	0.05	
	Min:	0.3	3.0	11.3	7.00	
	Max:	0.9	8.0	12.3	7.16	

Table 65. Measured O_2, Temperature and pH values in effluent at *School* on 25-1-2011

	Composite Sample Label:	School-Effluent-25-1-2011
Location: School (T2)	**Type:** Effluent	**Date:** 25-1-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T2-E-1	10:00	5.8	47	7.3	6.77	Clear water, rubbish floating on top
T2-E-2	11:50	5.8	47	7.7	6.73	Very little outflow
T2-E-3	13:46	5.3	45	7.9	6.82	Very little outflow
T2-E-4	15:13	5.6	46	7.6	6.66	Very little outflow
T2-E-5	16:47	5.6	46	7.3	6.74	Very little outflow
T2-E-6	18:20	5.7	47	7.0	6.88	Very little outflow
	***n*:**	6	6	6	6	
	Mean:	5.6	46.3	7.5	6.77	
	STD:	0.2	0.8	0.3	0.08	
	Min:	5.3	45.0	7.0	6.66	
	Max:	5.8	47.0	7.9	6.88	

Table 66. Measured O_2, Temperature and pH values in influent at *School* on 25-1-2011

	Composite Sample Label:	School-Influent-25-1-2011
Location: School (T2)	**Type:** Influent	**Date:** 25-1-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T2-I-1	9:45	1.0	9	11.2	7.01	Inflow
T2-I-2	11:40	0.8	7	11.5	6.87	Inflow
T2-I-3	13:34	0.9	8	11.8	7.02	Collection tank almost full, inflow
T2-I-4	15:05	1.1	10	11.8	6.89	Collection tank almost full, no inflow
T2-I-5	16:35	1.1	9	10.4	6.94	Collection tank almost full, no inflow
T2-I-6	18:07	1.1	10	10.9	7.12	Collection tank almost full, no inflow
	19:20					Pumping, inflow
	***n*:**	6	6	6	6	
	Mean:	1.0	8.8	11.3	6.98	
	STD:	0.1	1.2	0.6	0.09	
	Min:	0.8	7.0	10.4	6.87	
	Max:	1.1	10.0	11.8	7.12	

Table 67. Measured O_2, Temperature and pH values in effluent at *School* on 26-1-2011

	Composite Sample Label:	School-Effluent-26-1-2011
Location: School (T2)	**Type:** Effluent	**Date:** 26-1-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T2-E-1	9:55	5.3	43	6.9	6.92	Water salamander in sampling container
T2-E-2	11:30	5.6	45	7.2	6.87	---
T2-E-3	12:46	5.5	45	7.2	6.92	Students have swimming lessons
T2-E-4	14:10	5.3	44	7.4	6.82	---
T2-E-5	15:42	3.5	28	7.0	6.81	High outflow, sample taken from outflow stream; teachers comment on HF being green in first half and dry in second half in summer
T2-E-6	17:11	3.5	28	7.0	6.83	Outflow, taken from outflow stream
T2-E-7	19:15	4.3	35	7.0	6.87	---
	***n*:**	7	7	7	7	
	Mean:	4.7	38.3	7.1	6.86	
	STD:	0.9	7.8	0.2	0.05	
	Min:	3.5	28.0	6.9	6.81	
	Max:	5.6	45.0	7.4	6.92	

Table 68. Measured O_2, Temperature and pH values in influent at *School* on 26-1-2011

	Composite Sample Label:	School-Influent-26-1-2011
Location: School (T2)	**Type:** Influent	**Date:** 26-1-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T2-I-1	9:45	0.9	8	10.7	7.07	Collection tank at top of pump, inflow
T2-I-2	11:20	0.7	6	11.1	7.07	Collection tank almost full, inflow
T2-I-3	12:37	0.7	6	11.1	7.07	Collection tank almost full, no inflow
T2-I-4	14:00	0.6	5	11.1	7.01	Collection tank almost full, no inflow
T2-I-5	15:30	1.8	16	11.0	7.16	Collection tank empty, no inflow
T2-I-6	17:05	1.4	13	10.4	7.17	Collection tank low, inflow
T2-I-7	18:00	1.1	9	10.1	7.16	Collection tank at top of pump, inflow
	***n*:**	7	7	7	7	
	Mean:	1.0	9.0	10.8	7.10	
	STD:	0.4	4.1	0.4	0.06	
	Min:	0.6	5.0	10.1	7.01	
	Max:	1.8	16.0	11.1	7.17	

Table 69. Measured O_2, Temperature and pH values in effluent at *School* on 27-1-2011

	Composite Sample Label:	School-Effluent-27-1-2011
Location: School (T2)	**Type:** Effluent	**Date:** 27-1-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T2-E-1	9:33	6.1	48	6.4	6.81	Very little outflow (Collection tank is almost full)
T2-E-2	10:25	6.4	52	6.3	6.85	Very little outflow (Pumping at 10:30)
T2-E-3	11:15	4.2	33	6.2	6.79	Outflow, taken from outflow stream
T2-E-4	12:10	3.5	28	7.0	6.86	Outflow, taken from outflow stream
T2-E-5	13:20	4.0	33	6.8	6.93	Outflow, taken from outflow stream
T2-E-6	14:10	4.3	35	6.7	6.83	Outflow, taken from outflow stream
T2-E-7	15:10	4.5	36	6.9	6.97	Outflow, taken from outflow stream
T2-E-8	16:07	5.0	40	6.3	6.93	Outflow, taken from outflow stream
T2-E-9	17:15	5.1	41	6.4	6.88	Little outflow, taken from outflow stream
T2-E-10	18:05	5.6	44	6.0	6.80	Very little outflow, taken from outflow stream
T2-E-11	19:02	6.5	51	6.0	6.92	Almost no outflow
	***n*:**	11	11	11	11	
	Mean:	5.0	40.1	6.5	6.87	
	STD:	1.0	7.9	0.3	0.06	
	Min:	3.5	28.0	6.0	6.79	
	Max:	6.5	52.0	7.0	6.97	

Table 70. Measured O_2, Temperature and pH values in influent at *School* on 31-1-2011

	Composite Sample Label:	School-Influent-31-1-2011
Location: School (T2)	**Type:** Influent	**Date:** 31-1-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T2-I-1	8:45	0.7	6	10.8	7.14	Collection tank half, inflow
T2-I-2	9:30	1.0	8	10.7	7.16	Collection tank half, inflow
T2-I-3	10:20	0.7	6	10.7	7.14	Collection tank half, inflow
T2-I-4	11:15	0.6	5	10.8	7.19	Collection tank almost full, inflow
T2-I-5	12:27	0.6	6	11.0	7.19	Collection tank almost full, little inflow
T2-I-6	13:20	0.6	5	10.1	7.14	Collection tank almost full, no inflow
T2-I-7	14:40	0.6	5	10.9	7.21	Collection tank almost full, no inflow

	O2 mg/l	O2 %	Temp.	pH
***n*:**	7	7	7	7
Mean:	0.7	5.9	10.7	7.17
STD:	0.1	1.1	0.3	0.03
Min:	0.6	5.0	10.1	7.14
Max:	1.0	8.0	11.0	7.21

Table 71. Measured O_2, Temperature and pH values in effluent at *School* on 2-2-2011

	Composite Sample Label:	School-Effluent-2-2-2011
Location: School (T2)	**Type:** Effluent	**Date:** 2-2-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T2-E-1	9:45	7.4	57	5.3	6.98	No outflow
T2-E-2	11:10	5.1	40	5.0	7.01	Outflow, taken from outflow stream
T2-E-3	12:46	4.9	39	5.3	6.97	Outflow, taken from outflow stream
T2-E-4	14:15	5.7	44	5.1	6.99	Outflow, taken from outflow stream
T2-E-5	15:44	6.2	48	5.3	7.12	Little outflow, taken from outflow stream
T2-E-6	16:55	6.4	50	5.2	7.10	Little outflow, taken from outflow stream
T2-E-7	18:32	7.3	57	5.4	7.05	No outflow

	***n*:**	7	7	7	7	
	Mean:	6.1	47.9	5.2	7.03	
	STD:	1.0	7.4	0.1	0.06	
	Min:	4.9	39.0	5.0	6.97	
	Max:	7.4	57.0	5.4	7.12	

Table 72. Measured O_2, Temperature and pH values in influent at *School* on 2-2-2011

	Composite Sample Label:	School-Influent-2-2-2011
Location: School (T2)	**Type:** Influent	**Date:** 2-2-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T2-I-1	9:35	0.7	6	10.6	7.15	Collection tank almost full, no inflow
T2-I-2	11:00	2.2	19	10.5	7.25	Collection tank low, inflow; water on HF
T2-I-3	12:35	1.7	15	10.7	7.32	Collection tank low, inflow
T2-I-4	14:05	1.2	10	10.5	7.25	Collection tank low, inflow
T2-I-5	15:30	0.9	7	10.3	7.49	Collection tank low, inflow
T2-I-6	16:50	0.9	7	10.4	7.52	Collection tank low, no inflow
T2-I-7	18:20	0.8	7	10.5	7.44	Collection tank half, inflow
	***n*:**	7	7	7	7	
	Mean:	1.2	10.1	10.5	7.35	
	STD:	0.6	5.0	0.1	0.14	
	Min:	0.7	6.0	10.3	7.15	
	Max:	2.2	19.0	10.7	7.52	

Table 73. Measured O_2, Temperature and pH values in effluent at *School* on 3-2-2011

	Composite Sample Label:	School-Effluent-3-2-2011
Location: School (T2)	**Type:** Effluent	**Date:** 3-2-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T2-E-1	9:50	4.8	38	5.8	7.00	Outflow, taken from outflow stream
T2-E-2	11:06	5.3	42	5.9	7.03	Outflow, taken from outflow stream
T2-E-3	12:40	6.2	50	6.4	7.10	Outflow, taken from outflow stream
T2-E-4	14:17	6.1	50	6.4	7.00	Less outflow, taken from outflow stream
T2-E-5	15:44	6.5	53	6.3	7.07	Very little outflow, taken from outflow stream
T2-E-6	16:55	6.4	52	6.1	7.03	Very little outflow, taken from outflow stream
T2-E-7	18:27	7.1	56	5.6	7.07	Very little outflow, taken from outflow stream
	***n*:**	7	7	7	7	
	Mean:	6.1	48.7	6.1	7.04	
	STD:	0.8	6.4	0.3	0.04	
	Min:	4.8	38.0	5.6	7.00	
	Max:	7.1	56.0	6.4	7.10	

Table 74. Measured O_2, Temperature and pH values in influent at *School* on 3-2-2011

	Composite Sample Label:	School-Influent-3-2-2011
Location: School (T2)	**Type:** Influent	**Date:** 3-2-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T2-I-1	9:40	2.0	18	11.5	7.20	Collection tank low, inflow
T2-I-2	10:55	1.5	13	11.4	7.27	Collection tank low, inflow
T2-I-3	12:30	1.2	10	11.7	7.30	Collection tank low, inflow
T2-I-4	14:05	0.9	8	11.6	7.32	Collection tank low, inflow
T2-I-5	15:31	0.8	7	11.5	7.30	Collection tank half, no inflow
T2-I-6	16:43	0.8	7	11.1	7.29	Collection tank half, no inflow
T2-I-7	18:16	0.6	6	10.8	7.33	Collection tank almost full, inflow

***n*:**	7	7	7	7	
Mean:	1.1	9.9	11.4	7.29	
STD:	0.5	4.3	0.3	0.04	
Min:	0.6	6.0	10.8	7.20	
Max:	2.0	18.0	11.7	7.33	

Table 75. Measured O_2, Temperature and pH values in effluent at *School* on 4-2-2011

	Composite Sample Label:	School-Effluent-4-2-2011
Location: School (T2)	**Type:** Effluent	**Date:** 4-2-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T2-E-1	9:00	6.0	48	6.5	6.96	Very little outflow, taken from outflow stream
T2-E-2	9:50	6.6	53	6.3	6.99	Very little outflow, taken from outflow stream
T2-E-3	10:30	6.4	51	6.2	6.99	Very little outflow, taken from outflow stream
T2-E-4	11:10	6.4	51	6.2	6.98	Very little outflow, taken from outflow stream
T2-E-5	11:50	6.5	52	6.4	6.98	Very little outflow, taken from outflow stream
T2-E-6	12:25	6.5	53	6.5	6.99	Very little outflow, taken from outflow stream
T2-E-7	13:02	6.8	55	6.5	6.98	Very little outflow, taken from outflow stream
T2-E-8	13:42	6.7	54	6.2	6.97	Very little outflow, taken from outflow stream

***n*:**	8	8	8	8	
Mean:	6.5	52.1	6.4	6.98	
STD:	0.2	2.2	0.1	0.01	
Min:	6.0	48.0	6.2	6.96	
Max:	6.8	55.0	6.5	6.99	

Appendix 15. Summary and Graphical Representation of Measured O_2, pH and Temperature Values in Influent and Effluent at *Unie*

Table 76. Statistical representation of measured O_2 (mg/l) values in influent at *Unie*

	n	Mean	Std. Deviation	Minimum	Maximum
		mg/l	mg/l	mg/l	mg/l
Unie-Influent-24-1-2011	11	3.8	0.4	3.4	4.5
Unie-Influent-25-1-2011	5	4.1	0.1	4.0	4.2
Unie-Influent-26-1-2011	7	4.0	0.4	3.4	4.4
Unie-Influent-31-1-2011	7	2.8	0.5	2.0	3.6
Unie-Influent-2-2-2011	7	2.9	0.4	2.4	3.3
Unie-Influent-3-2-2011	7	3.2	0.3	2.8	3.8
Week 4	23	4.0	0.4	3.4	4.5
Week 5	21	3.0	0.4	2.0	3.8
Total	44	3.5	0.6	2.0	4.5

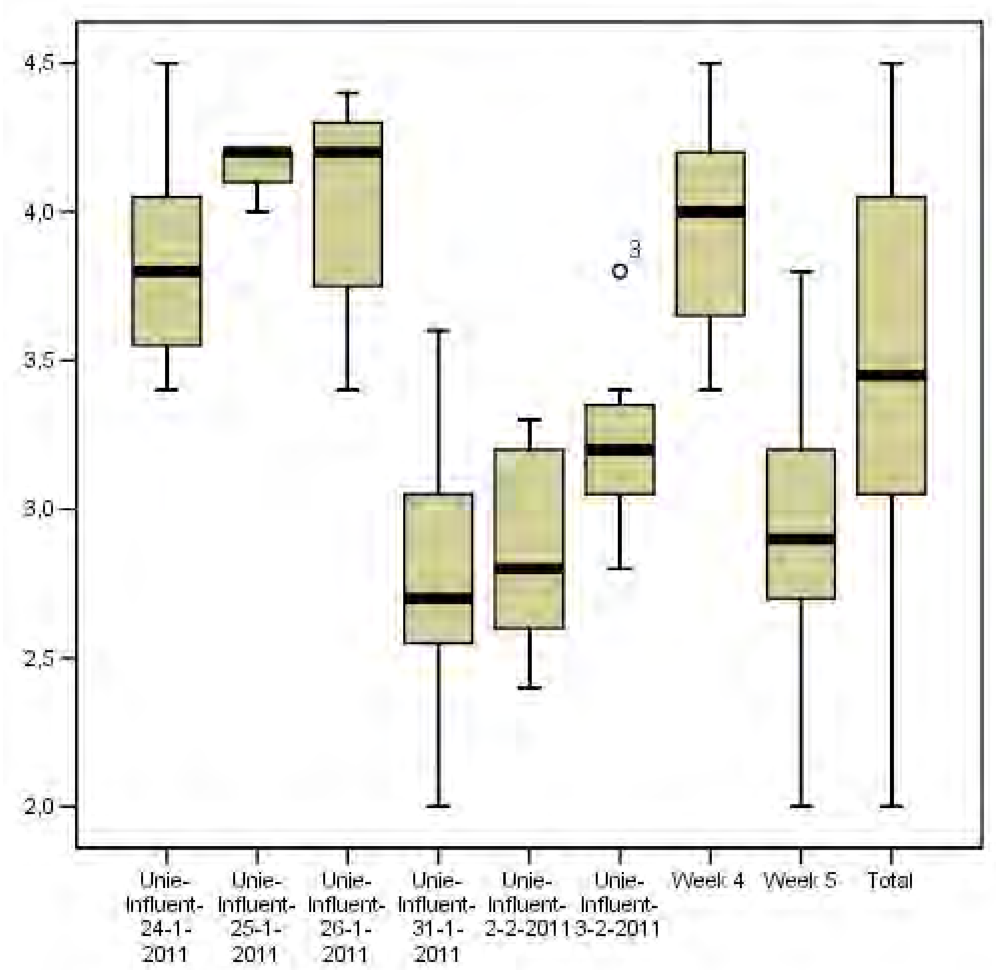

Figure 35. Box plot of measured O_2 (mg/l) values in influent at *Unie*

Table 77. Statistical representation of measured O_2 (mg/l) values in effluent at *Unie*

	n	Mean	Std. Deviation	Minimum	Maximum
		mg/l	mg/l	mg/l	mg/l
Unie-Effluent-25-1-2011	5	5.0	0.4	4.4	5.4
Unie-Effluent-26-1-2011	7	4.9	0.2	4.7	5.2
Unie-Effluent-27-1-2011	11	3.9	0.2	3.6	4.1
Unie-Effluent-2-2-2011	7	5.4	0.3	5.0	5.8
Unie-Effluent-3-2-2011	7	5.1	0.2	4.8	5.4
Unie-Effluent-4-2-2011	8	5.0	0.1	4.8	5.2
Week 4	23	4.5	0.6	3.6	5.4
Week 5	22	5.2	0.3	4.8	5.8
Total	45	4.8	0.6	3.6	5.8

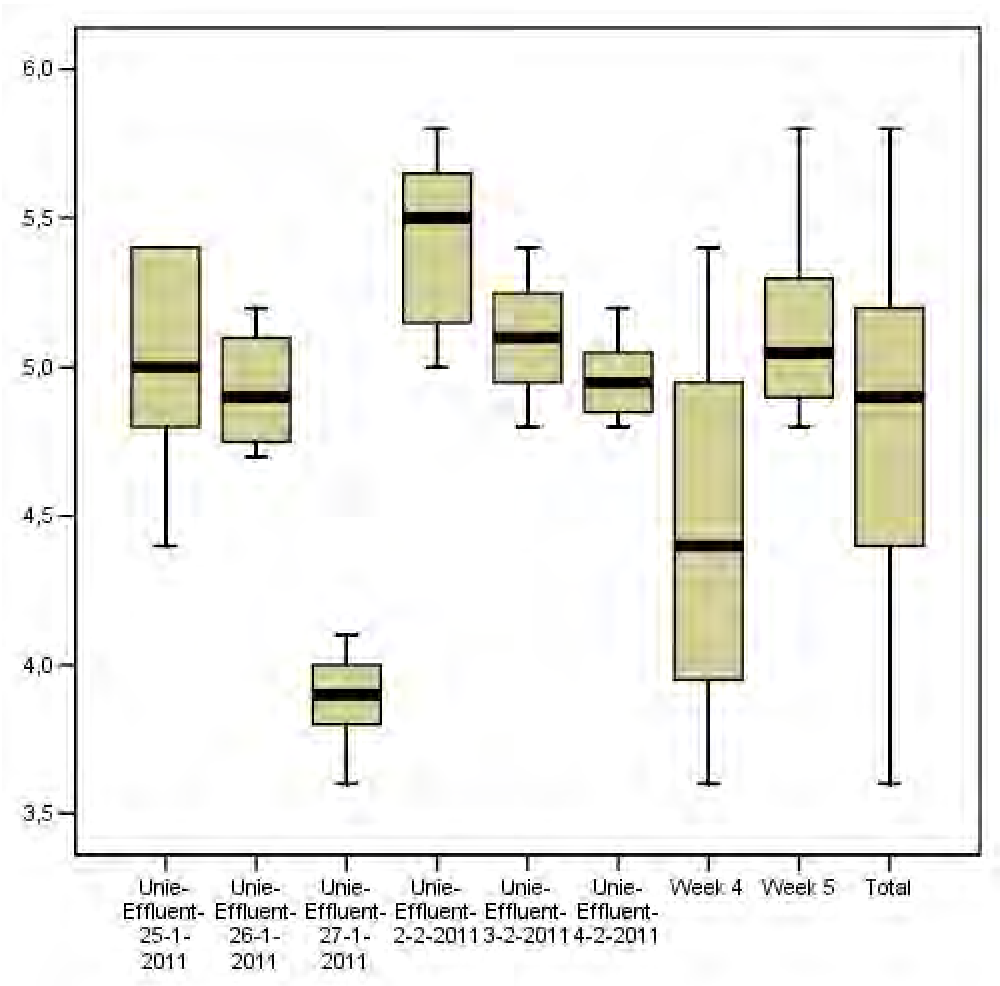

Figure 36. Box plot of measured O_2 (mg/l) values in effluent at *Unie*

Table 78. Statistical representation of measured pH (-) values in influent at *Unie*

	n	Mean	Std. Deviation	Minimum	Maximum
		-	-	-	-
Unie-Influent-24-1-2011	11	7.21	0.05	7.13	7.27
Unie-Influent-25-1-2011	5	7.19	0.11	7.12	7.38
Unie-Influent-26-1-2011	7	7.28	0.04	7.23	7.35
Unie-Influent-31-1-2011	7	7.26	0.05	7.18	7.32
Unie-Influent-2-2-2011	7	7.33	0.05	7.26	7.40
Unie-Influent-3-2-2011	7	7.27	0.05	7.22	7.33
Week 4	23	7.23	0.07	7.12	7.38
Week 5	21	7.29	0.06	7.18	7.40
Total	44	7.26	0.07	7.12	7.40

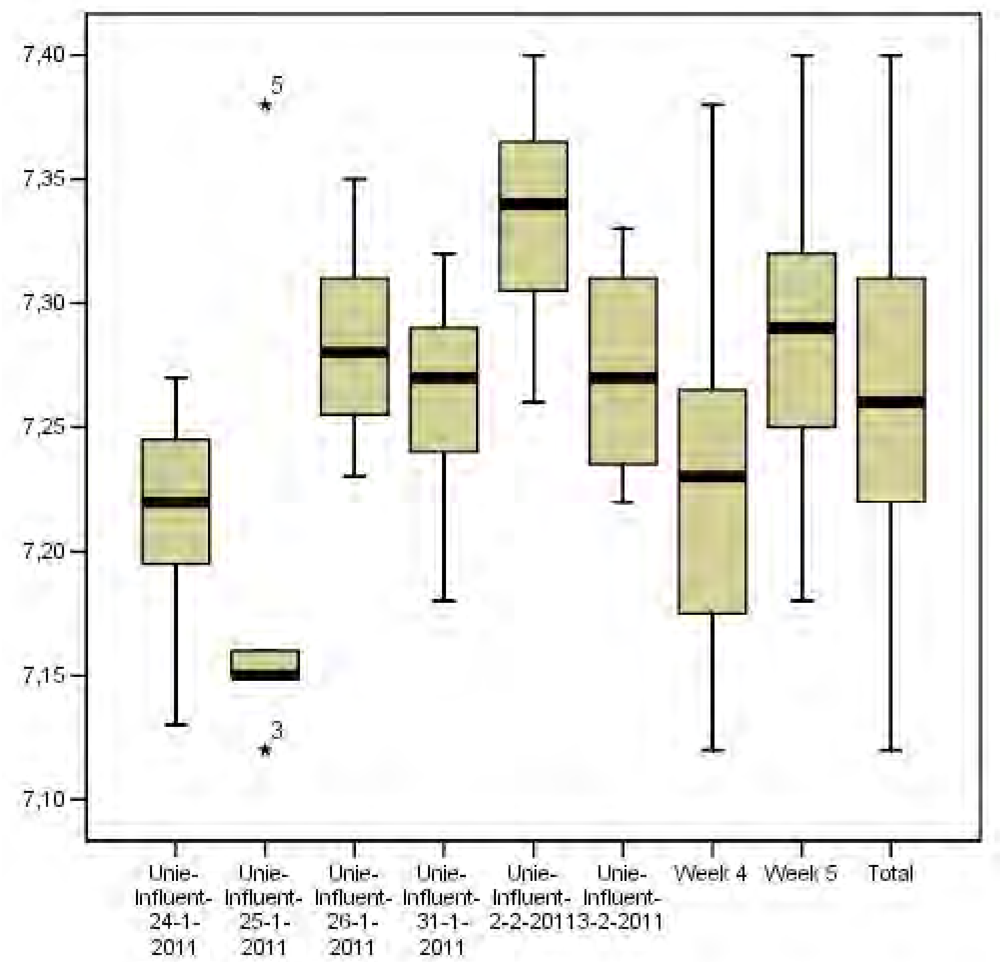

Figure 37. Box plot of measured pH (-) values in influent at *Unie*

Table 79. Statistical representation of measured pH (-) values in effluent at *Unie*

	n	Mean	Std. Deviation	Minimum	Maximum
		-	-	-	-
Unie-Effluent-25-1-2011	5	7.09	0.10	7.02	7.27
Unie-Effluent-26-1-2011	7	7.21	0.04	7.15	7.29
Unie-Effluent-27-1-2011	11	7.03	0.07	6.93	7.12
Unie-Effluent-2-2-2011	7	7.31	0.04	7.25	7.35
Unie-Effluent-3-2-2011	7	7.25	0.05	7.16	7.30
Unie-Effluent-4-2-2011	8	7.12	0.04	7.07	7.21
Week 4	23	7.10	0.11	6.93	7.29
Week 5	22	7.22	0.09	7.07	7.35
Total	45	7.16	0.12	6.93	7.35

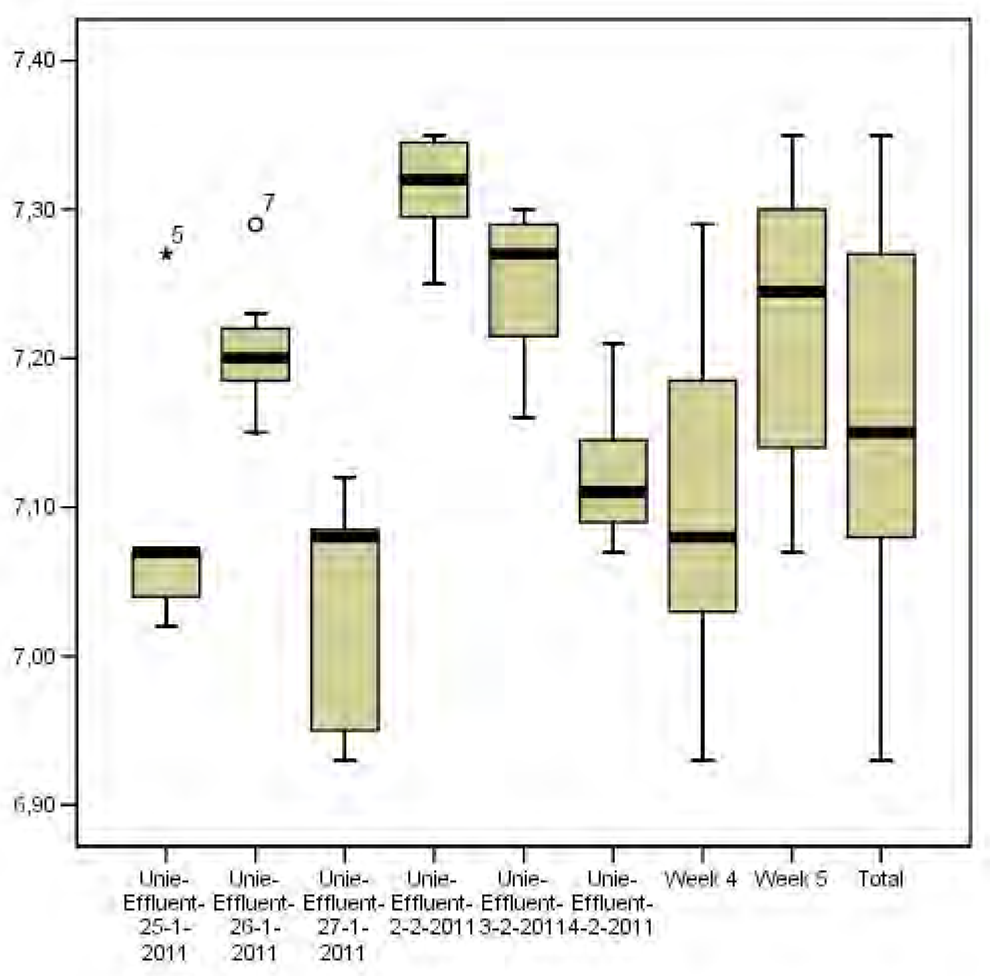

Figure 38. Box plot of measured pH (-) values in effluent at *Unie*

Table 80. Statistical representation of measured temperature (°C) values in influent at *Unie*

	n	Mean	Std. Deviation	Minimum	Maximum
		°C	°C	°C	°C
Unie-Influent-24-1-2011	11	10.2	0.4	9.6	10.6
Unie-Influent-25-1-2011	5	9.3	0.5	8.8	10.0
Unie-Influent-26-1-2011	7	9.4	0.3	9.0	9.7
Unie-Influent-31-1-2011	7	9.6	0.2	9.3	9.8
Unie-Influent-2-2-2011	7	9.3	0.1	9.2	9.5
Unie-Influent-3-2-2011	7	9.9	0.4	9.4	10.3
Week 4	23	9.8	0.5	8.8	10.6
Week 5	21	9.6	0.3	9.2	10.3
Total	44	9.7	0.5	8.8	10.6

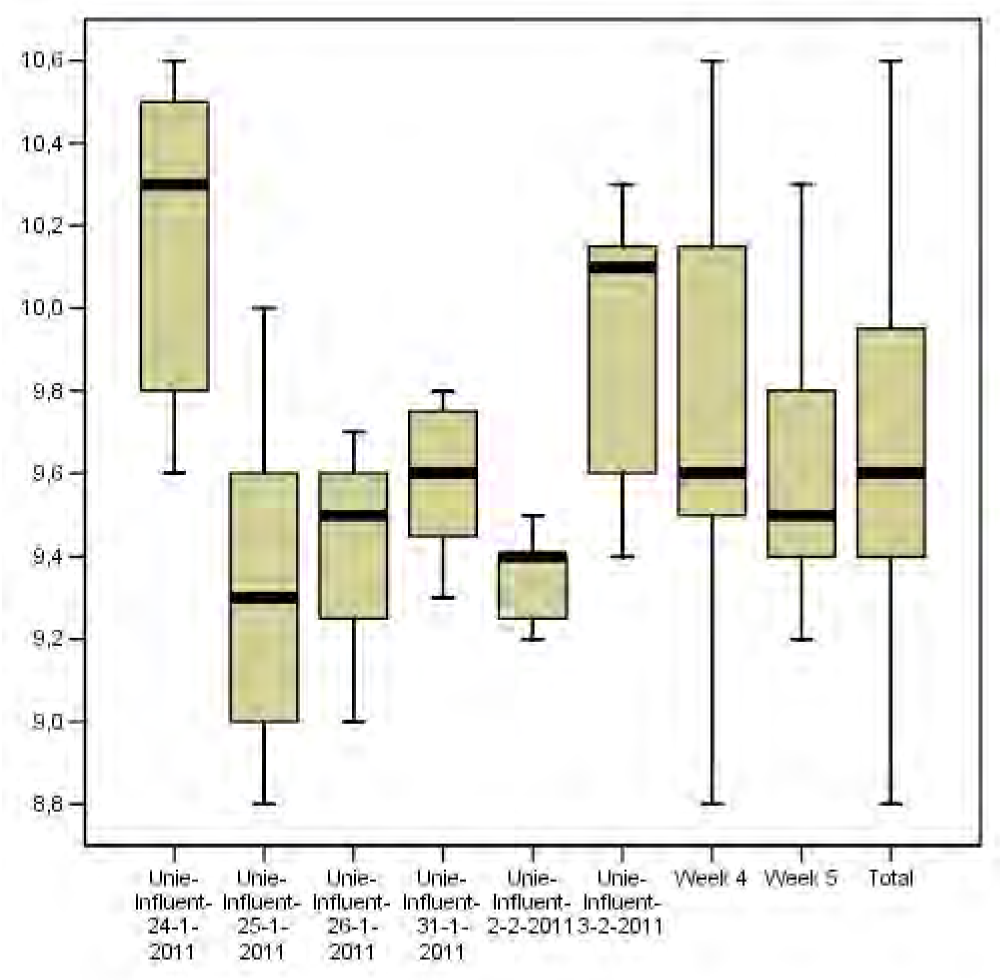

Figure 39. Box plot of measured temperature (°C) values in influent at Unie

Table 81. Statistical representation of measured temperature (°C) values in effluent at *Unie*

	n	Mean	Std. Deviation	Minimum	Maximum
		°C	°C	°C	°C
Unie-Effluent-25-1-2011	5	6.3	0.5	5.8	6.8
Unie-Effluent-26-1-2011	7	6.0	0.3	5.7	6.3
Unie-Effluent-27-1-2011	11	5.5	0.2	5.3	6.0
Unie-Effluent-2-2-2011	7	5.0	0.1	4.9	5.1
Unie-Effluent-3-2-2011	7	5.5	0.4	4.8	6.0
Unie-Effluent-4-2-2011	8	5.6	0.2	5.4	5.9
Week 4	23	5.8	0.4	5.3	6.8
Week 5	22	5.4	0.4	4.8	6.0
Total	45	5.6	0.5	4.8	6.8

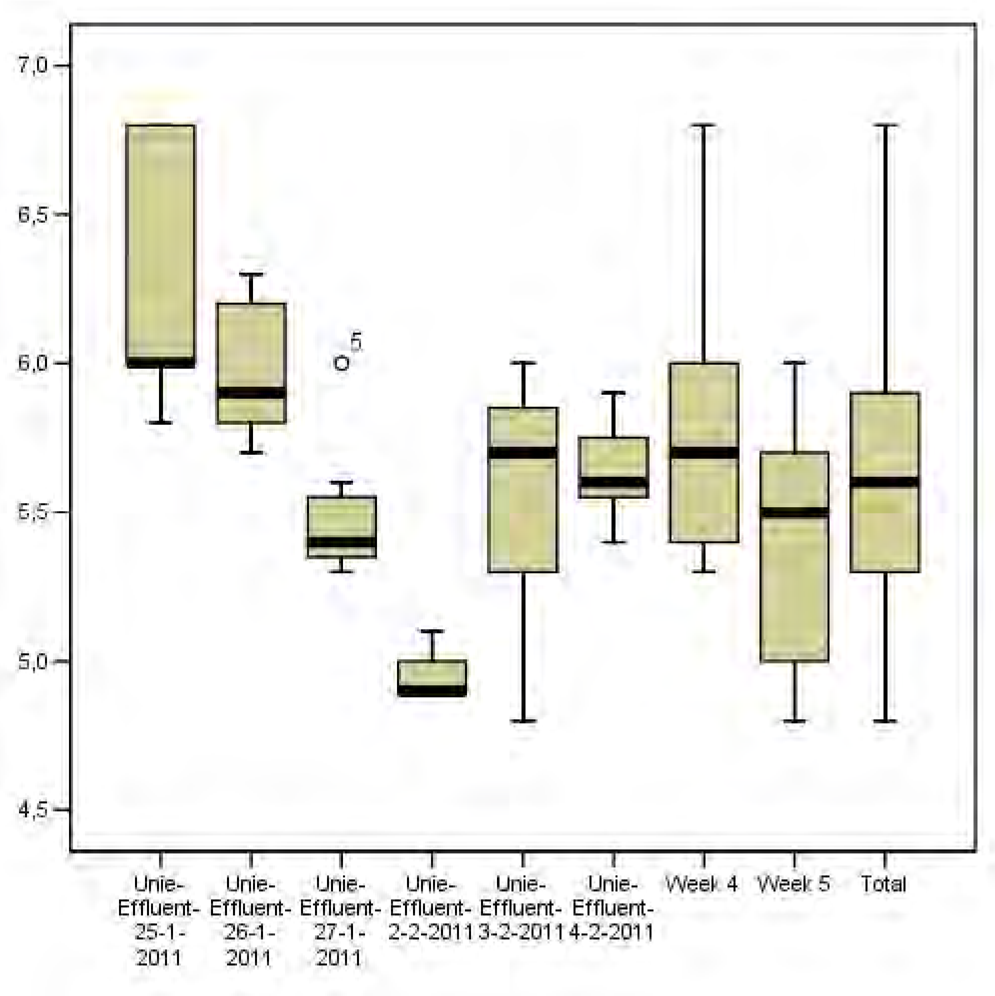

Figure 40. Box plot of measured temperature (°C) values in effluent at *Unie*

Appendix 16. Measured O_2, Temperature and pH Values in Influent and Effluent at *Unie*

Table 82. Measured O_2, Temperature and pH values in influent at *Unie* on 24-1-2011

	Composite Sample Label:	Unie-Influent-24-1-2011
Location: Unie (T3)	**Type:** Influent	**Date:** 24-1-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T3-I-1	8:40	3.6	32	10.5	7.13	Collection tank empty, inflow
T3-I-2	9:26	3.4	30	10.5	7.13	Collection tank low, inflow
T3-I-3	---	---	---	---	---	Stuck with car
T3-I-4	---	---	---	---	---	Stuck with car
T3-I-5	12:33	3.7	32	10.5	7.20	Collection tank low, inflow
T3-I-6	13:33	3.8	33	10.6	7.25	Inflow
T3-I-7	14:31	3.9	34	10.6	7.22	Inflow
T3-I-8	15:26	3.4	30	10.3	7.26	Inflow
T3-I-9	16:35	4.5	39	9.9	7.19	Collection tank empty, no inflow
T3-I-10	17:20	4.4	38	9.9	7.27	Inflow
T3-I-11	18:32	4.0	34	9.7	7.21	Inflow
T3-I-12	19:32	3.5	30	9.6	7.24	Inflow
T3-I-13	20:13	4.1	35	9.6	7.22	Collection tank empty, inflow
	***n*:**	11	11	11	11	
	Mean:	3.8	33.4	10.2	7.21	
	STD:	0.4	3.1	0.4	0.05	
	Min:	3.4	30.0	9.6	7.13	
	Max:	4.5	39.0	10.6	7.27	

Table 83. Measured O_2, Temperature and pH values in effluent at *Unie* on 25-1-2011

	Composite Sample Label:	Unie-Effluent-25-1-2011
Location: Unie (T3)	**Type:** Effluent	**Date:** 25-1-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T3-E-1	12:20	5.4	43	6.0	7.07	Flow is yellowish
T3-E-2	14:05	4.8	39	6.8	7.07	---
T3-E-3	---	---	---	---	---	---
T3-E-4	15:40	4.4	35	6.8	7.02	---
T3-E-5	17:10	5.4	43	6.0	7.04	---
T3-E-6	18:55	5.0	39	5.8	7.27	---
	***n*:**	5	5	5	5	
	Mean:	5.0	39.8	6.3	7.09	
	STD:	0.4	3.3	0.5	0.10	
	Min:	4.4	35.0	5.8	7.02	
	Max:	5.4	43.0	6.8	7.27	

Table 84. Measured O_2, Temperature and pH values in influent at *Unie* on 25-1-2011

	Composite Sample Label:	Unie-Influent-25-1-2011
Location: Unie (T3)	**Type:** Influent	**Date:** 25-1-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T3-I-1	12:05	4.0	34	9.6	7.16	Inflow (at 10:15 and 11:00 as well)
T3-I-2	13:55	4.2	37	10.0	7.15	Collection tank empty, no inflow
T3-I-3	---	---	---	---	---	At garage for repairs
T3-I-4	15:35	4.2	36	9.3	7.12	Collection tank half, no inflow
T3-I-5	16:56	4.1	34	9.0	7.15	Collection tank half, no inflow (pH meter status bar is empty)
T3-I-6	18:48	4.2	36	8.8	7.38	Collection tank empty, inflow
	***n*:**	5	5	5	5	
	Mean:	4.1	35.4	9.3	7.19	
	STD:	0.1	1.3	0.5	0.11	
	Min:	4.0	34.0	8.8	7.12	
	Max:	4.2	37.0	10.0	7.38	

Table 85. Measured O_2, Temperature and pH values in effluent at *Unie* on 26-1-2011

	Composite Sample Label:	Unie-Effluent-26-1-2011
Location: Unie (T3)	**Type:** Effluent	**Date:** 26-1-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T3-E-1	10:15	5.0	40	5.9	7.21	---
T3-E-2	11:55	5.2	41	6.1	7.23	---
T3-E-3	13:12	4.7	38	6.3	7.20	---
T3-E-4	14:36	5.2	41	6.3	7.15	---
T3-E-5	16:05	4.8	38	5.9	7.19	Yellow colour is Fe? P binds to Fe, could this result in higher P-total levels?
T3-E-6	17:36	4.9	38	5.7	7.18	---
T3-E-7	18:46	4.7	37	5.7	7.29	---
	***n*:**	7	7	7	7	
	Mean:	4.9	39.0	6.0	7.21	
	STD:	0.2	1.6	0.3	0.04	
	Min:	4.7	37.0	5.7	7.15	
	Max:	5.2	41.0	6.3	7.29	

Table 86. Measured O_2, Temperature and pH values in influent at *Unie* on 26-1-2011

	Composite Sample Label:	Unie-Influent-26-1-2011
Location: Unie (T3)	**Type:** Influent	**Date:** 26-1-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T3-I-1	10:10	4.2	36	9.6	7.28	Collection tank half, inflow
T3-I-2	11:50	4.4	38	9.7	7.31	Collection tank empty, inflow
T3-I-3	13:05	4.4	38	9.6	7.23	Collection tank low, inflow
T3-I-4	14:25	3.4	29	9.5	7.25	Collection tank half (above pump), inflow
T3-I-5	15:55	3.9	34	9.5	7.31	Collection tank low (below pump), inflow
T3-I-6	17:25	4.2	36	9.0	7.26	Collection tank low, inflow
T3-I-7	18:31	3.6	36	9.0	7.35	Collection tank low, little inflow

	***n*:**	7	7	7	7
	Mean:	4.0	35.3	9.4	7.28
	STD:	0.4	3.1	0.3	0.04
	Min:	3.4	29.0	9.0	7.23
	Max:	4.4	38.0	9.7	7.35

Table 87. Measured O_2, Temperature and pH values in effluent at *Unie* on 27-1-2011

	Composite Sample Label:	Unie-Effluent-27-1-2011
Location: Unie (T3)	**Type:** Effluent	**Date:** 27-1-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T3-E-1	9:47	3.8	30	5.4	6.98	Constant outflow
T3-E-2	10:40	3.8	30	5.3	7.12	Constant outflow
T3-E-3	11:30	4.1	32	5.5	7.08	Constant outflow
T3-E-4	12:25	3.7	29	5.6	6.95	Constant outflow
T3-E-5	13:35	3.6	28	6.0	6.93	Constant outflow
T3-E-6	14:25	4.1	32	5.6	6.95	Constant outflow
T3-E-7	15:35	3.9	31	5.4	6.95	Constant outflow
T3-E-8	16:26	3.9	31	5.3	7.10	Constant outflow
T3-E-9	17:30	4.0	31	5.4	7.09	Constant outflow
T3-E-10	18:18	4.0	31	5.3	7.08	Constant outflow
T3-E-11	19:20	4.0	31	5.4	7.08	Constant outflow

	***n*:**	11	11	11	11
	Mean:	3.9	30.5	5.5	7.03
	STD:	0.2	1.2	0.2	0.07
	Min:	3.6	28.0	5.3	6.93
	Max:	4.1	32.0	6.0	7.12

Table 88. Measured O_2, Temperature and pH values in influent at *Unie* on 31-1-2011

	Composite Sample Label:	Unie-Influent-31-1-2011
Location: Unie (T3)	**Type:** Influent	**Date:** 31-1-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T3-I-1	9:00	2.6	23	9.7	7.18	Collection tank half, inflow
T3-I-2	9:45	2.5	22	9.5	7.23	Pumping, inflow
T3-I-3	10:35	3.2	27	9.4	7.25	Collection tank empty, inflow
T3-I-4	11:30	3.6	31	9.6	7.27	Collection tank empty, inflow; water still on HF-frozen
T3-I-5	12:40	2.9	26	9.8	7.32	Collection tank low, little inflow
T3-I-6	13:35	2.7	23	9.3	7.28	Collection tank low, little inflow
T3-I-7	14:55	2.0	17	9.8	7.30	Collection tank low, little inflow

	***n*:**	7	7	7	7
	Mean:	2.8	24.1	9.6	7.26
	STD:	0.5	4.4	0.2	0.05
	Min:	2.0	17.0	9.3	7.18
	Max:	3.6	31.0	9.8	7.32

Table 89. Measured O_2, Temperature and pH values in effluent at *Unie* on 2-2-2011

	Composite Sample Label:	Unie-Effluent-2-2-2011
Location: Unie (T3)	**Type:** Effluent	**Date:** 2-2-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T3-E-1	10:15	5.0	39	4.9	7.25	Yellow residue in outflow
T3-E-2	11:37	5.0	39	4.9	7.30	Foam on surface water
T3-E-3	13:20	5.6	44	4.9	7.34	---
T3-E-4	14:45	5.8	45	4.9	7.35	---
T3-E-5	16:10	5.5	43	5.1	7.32	---
T3-E-6	17:23	5.7	44	5.0	7.35	---
T3-E-7	18:55	5.3	41	5.0	7.29	---

	***n*:**	7	7	7	7
	Mean:	5.4	42.1	5.0	7.31
	STD:	0.3	2.5	0.1	0.04
	Min:	5.0	39.0	4.9	7.25
	Max:	5.8	45.0	5.1	7.35

Table 90. Measured O_2, Temperature and pH values in influent at *Unie* on 2-2-2011

	Composite Sample Label:	Unie-Influent-2-2-2011
Location: Unie (T3)	**Type:** Influent	**Date:** 2-2-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T3-I-1	10:00	2.5	21	9.4	7.26	Pumping, inflow
T3-I-2	11:25	3.2	27	9.5	7.29	Collection tank low, inflow
T3-I-3	13:04	3.2	27	9.2	7.32	Collection tank low, inflow
T3-I-4	14:30	2.4	20	9.3	7.36	Collection tank low, inflow
T3-I-5	15:55	3.3	29	9.4	7.40	Collection tank low, inflow
T3-I-6	17:08	2.8	25	9.4	7.37	Collection tank low, inflow
T3-I-7	18:44	2.7	23	9.2	7.34	Collection tank low, inflow
	***n*:**	7	7	7	7	
	Mean:	2.9	24.6	9.3	7.33	
	STD:	0.4	3.4	0.1	0.05	
	Min:	2.4	20.0	9.2	7.26	
	Max:	3.3	29.0	9.5	7.40	

Table 91. Measured O_2, Temperature and pH values in effluent at *Unie* on 3-2-2011

	Composite Sample Label:	Unie-Effluent-3-2-2011
Location: Unie (T3)	**Type:** Effluent	**Date:** 3-2-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T3-E-1	10:20	5.1	41	5.5	7.16	Foam on surface water
T3-E-2	11:30	4.9	39	5.7	7.24	---
T3-E-3	13:05	5.3	42	5.9	7.19	---
T3-E-4	14:46	5.4	43	6.0	7.27	---
T3-E-5	16:08	5.2	41	5.8	7.30	---
T3-E-6	17:15	5.0	39	5.1	7.30	---
T3-E-7	18:53	4.8	37	4.8	7.28	Cold sampling bottle?
	***n*:**	7	7	7	7	
	Mean:	5.1	40.3	5.5	7.25	
	STD:	0.2	2.1	0.4	0.05	
	Min:	4.8	37.0	4.8	7.16	
	Max:	5.4	43.0	6.0	7.30	

Table 92. Measured O_2, Temperature and pH values in influent at *Unie* on 3-2-2011

	Composite Sample Label:	Unie-Influent-3-2-2011
Location: Unie (T3)	**Type:** Influent	**Date:** 3-2-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T3-I-1	10:00	2.8	24	9.5	7.22	Collection tank low, inflow
T3-I-2	11:15	3.2	29	10.1	7.22	Collection tank empty, inflow; water still on HF
T3-I-3	12:55	3.8	34	10.3	7.27	Collection tank low, inflow
T3-I-4	14:30	2.9	26	10.2	7.25	Collection tank low, inflow
T3-I-5	15:55	3.3	29	10.1	7.33	Collection tank empty, inflow; water still on HF
T3-I-6	17:05	3.4	30	9.7	7.32	Collection tank empty, inflow
T3-I-7	18:38	3.2	29	9.4	7.30	Collection tank half, inflow

	***n*:**	7	7	7	7
	Mean:	3.2	28.7	9.9	7.27
	STD:	0.3	3.1	0.4	0.05
	Min:	2.8	24.0	9.4	7.22
	Max:	3.8	34.0	10.3	7.33

Table 93. Measured O_2, Temperature and pH values in effluent at *Unie* on 4-2-2011

	Composite Sample Label:	Unie-Effluent-4-2-2011
Location: Unie (T3)	**Type:** Effluent	**Date:** 4-2-2011

Aliquot label	Time	O2		Temp.	pH	Remarks
		mg/l	%	°C	-	
T3-E-1	9:18	5.1	40	5.7	7.21	---
T3-E-2	10:06	4.9	38	5.4	7.15	---
T3-E-3	10:45	4.8	38	5.5	7.10	---
T3-E-4	11:25	5.2	41	5.6	7.11	---
T3-E-5	12:00	4.9	39	5.8	7.07	---
T3-E-6	12:39	5.0	40	5.9	7.08	---
T3-E-7	13:13	5.0	39	5.6	7.11	Black solids in effluent
T3-E-8	13:58	4.8	39	5.6	7.14	---

	***n*:**	8	8	8	8
	Mean:	5.0	39.3	5.6	7.12
	STD:	0.1	1.0	0.2	0.04
	Min:	4.8	38.0	5.4	7.07
	Max:	5.2	41.0	5.9	7.21

Appendix 17. Influent and Effluent Characteristics of Wastewater Treated by the Wastewater Treatment Plant in Culemborg

Table 94. Characteristics of the influent from the wastewater treatment plant in Culemborg from 3-1-2011 till 30-4-2011 (Kleibergen, 2011c)

Date	Laboratory Code	Discharge	BOD_5	COD	TKN	P-total	TSS	pH
		m^3/d	mg/l	mg/l	mg/l	mg/l	mg/l	-
3-1-2011	2010-018815	---	160	425	43	5.7	130	8.0
6-2-2011	2011-001909	---	205	510	47	6.3	130	7.9
17-2-2011	2011-002497	---	145	410	42	5.8	160	8.0
25-2-2011	2011-000924	---	135	310	36	4.7	100	7.9
4-3-2011	2011-003485	---	115	245	34	4.3	100	7.9
19-3-2011	2011-004521	---	190	460	49	6.6	160	7.8
31-3-2011	2011-004955	---	285	805	50	8.3	290	7.8
27-4-2011	2011-005774	---	245	585	62	8.3	250	7.7
30-4-2011	2011-006375	---	260	455	55	6.7	310	7.8
	n:	0	9	9	9	9	9	9
	Mean:	---	193	467	46	6.3	181	7.9
	STD:	---	60	162	9	1.4	81	0.1
	Min:	---	115	245	34	4.3	100	7.7
	Max:	---	285	805	62	8.3	310	8.0

Table 95. Characteristics of the effluent from the wastewater treatment plant in Culemborg from 3-1-2011 till 3-5-2011 (Kleibergen, 2011c)

Date	Laboratory Code	Discharge	BOD_5	COD	N-total[41]	TKN	NO_3^-	NO_2^-	P-total	TSS	pH	SO_4	Cl
		m^3/d	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	-	mg/l	mg/l
3-1-2011	2010-018816	11681	2.2	20	6.0	1.7	4.10	0.24	2.10	<2.0	7.9	26	87
16-1-2011	2011-000549	19361	1.8	16	1.7	1.7							
25-1-2011	2011-000954	17344	<1.0	21	1.7	1.7							
6-2-2011	2011-001910	10672	1.8	19	5.1	2.1	2.80	0.23	2.50	<2.0	7.8	34	92
12-2-2011	2011-002396	12658	1.6	16	1.5	1.5							
17-2-2011	2011-002498	10806	1.6	27	3.9	1.8	1.90	0.15	1.40	<2.0	7.9		
25-2-2011	2011-000925	10475	2.2	26	8.5	2.2	6.10	0.18	2.50	2.8	7.7		
27-2-2011	2011-003430	18995	5.6	35	4.4	4.4							
4-3-2011	2011-003486	11914	3.0	20	8.6	1.9	6.30	0.35	0.99	3.8	7.9	34	84
11-3-2011	2011-003891	10428	1.4	28	1.8	1.8							
19-3-2011	2011-004522	10818	3.0	24	4.5	2.0	2.40	0.13	2.00	4.0	8.0		
22-3-2011	2011-004544	10188	2.2	29	2.0	2.0							
31-3-2011	2011-004956	15917	2.6	26	6.3	2.8	3.40	0.11	2.60	2.2	8.1	34	78
4-4-2011	2011-005540	10719	1.8	30	1.6	1.6							
20-4-2011	2011-006054	10392	2.0	30	2.7	2.7							
27-4-2011	2011-005775	9961	2.6	28	3.5	2.1	1.20	0.15	2.50	6.8	7.7		
30-4-2011	2011-006376	10850	2.0	32	3.0	2.1	0.85	0.08	1.90	5.0	7.9	33	84
3-5-2011	2011-006436	8775	1.2	30	1.9	1.9							
	n:	18	18	18	18	18	9	9	9	9	9	5	5
	Mean:	12331	<2.2	25	3.8	2.1	3.23	0.18	2.05	<3.4	7.9	32	85
	STD:	3239	1.0	6	2.3	0.7	1.96	0.08	0.56	1.7	0.1	3	5
	Min:	8775	<1.0	16	1.5	1.5	0.85	0.08	0.99	<2.0	7.7	26	78
	Max:	19361	5.6	35	8.6	4.4	6.30	0.35	2.60	6.8	8.1	34	92

[41] This concentration is calculated by adding TKN, NO_3^- and NO_2^-.

Appendix 18. List of Publications

Blom, J.J., Bulk, J. van de, Nanninga, T., (2010). *Verkenning kennis en ervaring grijswater.* Document prepared for STOWA meeting. Document number N001-4714360BLJ-V02. 9 (Two appendices: Literatuurlijst grijsafvalwaterzuivering in Nederland; Literatuurlijst grijsafvalwaterzuivering in het Buitenland).

Nanninga, T.A., (2011). Afvalwater zuiveren bij een waterwingebied. *Neerslag*, 46 (3): 29-32.

An article in H_2O based on the fieldwork done in Lanxmeer. This will be written in conjunction with E. Marsman (WSRL) and Tauw.