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TKI Loop-closure Cleantech Playground

Local water and energy solutions

KWR Watercycle Research Institute

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Summary

De Ceuvel in Amsterdam North is a former industrial plot that has been turned into a sustainable urban development. The heavily polluted site features retrofitted houseboats as offices, placed on land, surrounded by soil-cleaning plants. Because of the temporary character of the site (it is rented for 10 years) and the polluted soil, the houseboats are not connected to the sewer system. Instead they are provided with dry composting toilets and individual biofilters for grey water treatment. The boats still use conventional delivered drinking water. The primary goal of this pilot project, Cleantech Playground De Ceuvel, is to achieve local loop-closure of cycles in the city by applying innovative concepts and technological solutions. The performances of the water-related technology in particular, are monitored in this TKI project and evaluated in order to show the applicability in a sustainable circular economy. Self-sufficient neighbourhoods with their own, decentralised water supply add to the image of the circular economy. Local production of drinking water is evaluated by Life Cycle Assessment (LCA), Quantitative Microbial Risk Assessment (QMRA) and financial aspects. The individual grey water treatment plants, consisting of a settling module and biofilter module, as well as some other achievements of technology, like the applied composting toilets and urine treatment are monitored. Beside assessment of technology performance and development of new solutions for metropolitan areas, human aspects and interactions between users and clean technologies are also studied, to understand how communities can adapt to new systems and changes.

Composting toilets

Taking into account the goal of the research at De Ceuvel (local loop closure) and the lack of a sewer connection, composting toilets are being used in the office boats, so the users have to bring the faecal matter from the composting toilet periodically to a central composter. After 11 months composting, the level of *streptococci* in the composter was reduced by log 1.9. This does not yet meet the WHO recommendation of log 6 reduction by composting. Furthermore, user satisfaction regarding the composting toilets and the handling of human excreta is low, while the costs are higher compared to other (conventional) sanitation solutions. Application of composting toilets is not recommended in future developments.

Urine and nutrient recovery

Separately collected urine from the Café De Ceuvel was treated for nutrient recovery resulting in the formation of struvite. Research was performed on enhancing the nutrient content of struvite by using alternative nitrogen adsorbing materials (zeolite and biochar). In pot tests, the nutrients in biochar-based fertiliser were shown to be less available than zeolite-based fertilisers in the short-term. Urine was spiked with pharmaceuticals and recovered fertilisers were applied on tomato plants. Nutritional value of the recovered fertilisers was assessed through measures of plant growth. Uptake and accumulation of pharmaceuticals were measured in the tomatoes. The concentration of pharmaceuticals in tomatoes was below detection limits (0.02 mg/kg). These levels are far below the acceptable daily intake (ADI), which is 1% of the minimum therapeutic dose.

Grey water treatment

Since the houseboats are used as offices they do not have showers or washing machines, so only a minimum amount of five litres per capita per day is needed for drinking, food preparation and personal hygiene, compared to the current average of 25 litres in

conventional offices and 128 litres in households in The Netherlands (Pieterse-Quirijns *et al.* 2009). The produced grey water was treated in individual low-tech biofilters, consisting of two pallet tanks filled with a mixture of gravel and sand, topped up with reed. The effluent of the filters was monitored before it was infiltrated in the soil. The monitoring results comply with the Dutch standards for individual wastewater treatment systems.

Life Cycle Assessment (LCA) of (de)centralised drinking water supply

A LCA study obtained information on the environmental impact of drinking water production both in a centralised and decentralised scenario, specific for the operational aspects. The goal of both scenarios is to produce drinking water according to Dutch quality standards. For the centralised scenario the actual drinking water production at Weesperkarspel was used as a model. For De Ceuvel the following treatment scheme was designed: 1) raw water intake, 2) ultrafiltration, 3) nanofiltration, 4) UV disinfection and 5) remineralisation. The environmental impact is expressed as Ecopoints[1] for the production of 1 m^3 drinking water. Although the absolute values itself are very low, the production of decentralised drinking water has a higher environmental impact and corresponds to 0.104 Ecopoints. This is approximately 25% more than the centralised situation (0.0762 Ecopoints). The difference between these two scenarios becomes more significant (60%) when also the distribution network is included in the calculation. The environmental impact is strongly affected by the energy origin. Improvements in energy demand or (green) energy supply can be implemented both at centralised and decentralised scale and as such there is no difference in environmental impact. The fact that less drinking water is used at De Ceuvel does reduce the environmental impact of operations. The impact of infrastructure, especially distribution, is not affected by the use, since the momentary demand when opening a tap determines the design of this infrastructure.

Quantitative Microbial Risk Assessment (QMRA) of decentralised drinking water supply

Water companies in the Netherlands perform quantitative microbial risk assessment (QMRA) to verify that risk of infection is below 1 per 10,000 persons per year, which is the legal requirement (Smeets et al., 2010). The QMRA for decentralised drinking water production at De Ceuvel showed that it is possible to produce safe water in a decentralised system (risk of 7 infections per 100,000 persons). However, this requires advanced treatment technologies and strict monitoring and maintenance. The latter may be challenging for consumers with limited knowledge of health risks and applied technologies and results in high costs. Current (online) monitoring technologies are not capable yet to guarantee continuous safety in an independently operated decentralised system. Altogether, decentralised drinking water production is not recommended.

Financial and legislative issues

To ensure that the drinking water quality is guaranteed, a comprehensive monitoring program is needed, which will increase the costs, so it becomes difficult to still produce at acceptable costs. Current quality monitoring regulations appear to make decentralised drinking water production 3 to 10 fold more expensive compared to centralised drinking water production. Legislation requires every Individual Wastewater Treatment (IWT) system (15 small scale biofilters in the case of De Ceuvel) to be monitored 2 times per year on effluent quality, but there is still no clear process and agreement for the stakeholders of De Ceuvel project regarding who and how the quality monitoring of these systems should be performed. When labour costs for operation and maintenance are minimized by the deployment of volunteers in decentralised wastewater treatment, overall costs can be comparable with centralised treatment, but such a comparison is not completely fair and

[1] Thousand Ecopoints corresponds to the environmental impact of one Western European person per year.

certainly not advisable from a risk point of view. Furthermore, the current costs for centralised drinking water production and wastewater treatment includes several additional aspects, like costs for environmental protection, research & development and additional tax.

User behaviour

Feedback from users on De Ceuvel allows for a better understanding of which aspects of the clean technologies are problematic or satisfying. It is clear that the occurrence of uncontrolled phenomena such as smells and flies are not acceptable for users. It breaches the comfort level of conventional solutions they are used to. When solutions for each of these issues are implemented, the users are as happy with the clean technologies as they are with conventional systems. It can be concluded that a regular use of composting toilets is not recommended in the Netherlands, because of discomfort of the users, higher costs and the difficulty to safely reuse the compost. Taken into account the goal of the research at De Ceuvel (local loop-closure) and the lack of a sewer connection, the previous choice for composting toilets is understandable.

CONCLUSIONS

It can be concluded from this study that decentralised drinking water in an urban environment as De Ceuvel, with a temporary office function, is less sustainable and more costly than a centralised system and that the same level of safety cannot be guaranteed. However, when connection to a centralised system isn't possible or only at high cost, decentralised solutions can provide an alternative. Decentralised drinking water treatment systems generally have a higher energy requirement per cubic meter of water produced due to the small scale. By reducing the amount of water used, the total use of energy and thus environmental impact will be reduced. When sufficient, sustainable energy is available the total environmental impact and total cost can remain low. For large scale systems, reduced water use has limited effect since its costs and environmental impact depend more on the fixed assets.

Individual wastewater treatment as performed on De Ceuvel is more costly than current centralised wastewater treatment in The Netherlands. Nevertheless, grey water can be treated with low-tech biofiltration in individual water treatment systems to achieve sufficient water quality for discharge into the ground, based on Dutch regulation. The decentralised system at De Ceuvel allows for direct reuse of resources by e.g. composting faeces and recovering nutrients from urine. Composting of faecal matter in the Netherlands requires over 11 months, after which *streptococci* reduction still did not meet WHO recommendations. Short term experiments showed that urine-derived struvite is an excellent fertilizer. Struvite from urine spiked with pharmaceuticals didn't lead to detection of pharmaceuticals in tomatoes. However the long-term effects of using urine-derived struvite-sorbent fertilisers on soil quality should be investigated. Research should focus on uptake of contaminants by root crops, such as carrots or radishes, and leafy vegetables, such as lettuces. The alternative of using struvite to grow contaminated plant biomass as a feedstock for other purposes, such as compost or animal feed should also be investigated for long term health risks. Struvite-sorbent fertilisers could be developed further to optimize nutrient recovery from urine. Users seem to accept these initiatives if the level of comfort is comparable to conventional systems. Health and safety risks and related responsibilities for both water loop-closure and resource recovery are points of concern for decentralised systems, which cannot be solved by technology alone. New technologies need to address user behaviour and awareness to achieve safe decentralised systems. Legal and institutional aspects regarding local water treatment and loop-closure are under development and currently not always clear. Technically local loop-closure is feasible, and technological developments can shift the conditions at which decentralised systems are the preferred option in terms of costs and sustainability in the long term. Future research and experience with bigger, more representative projects addressing technology and user behaviour can use and further develop the decentralised concepts from the current study.

Overall, aspects that could be beneficially applied in future decentralised concepts can be identified from this TKI project and currently include:

- Site specific risk- and sustainability assessment of decentralised systems and loop-closure are needed to make appropriate choices for implementation.
- No decentralised drinking water production in an urban environment as De Ceuvel.
- No application of composting toilets, but more comfortable (new) sanitation solutions.
- Separated collection of wastewater streams and treatment has potential for e.g. direct reuse of resources.
- There is interest in rainwater use for e.g. flushing toilets, gardening, showering, and dish washers.

Contents

1 Introduction

1.1 Circular economy

Cities consume natural resources. Energy and raw materials are consumed and waste is produced. For more sustainable cities, it is necessary that water, food and energy are produced as efficiently as possible. Renewable sources or reuse play an important role and value elimination should be minimized in the system. The urban water cycle plays a crucial role requiring resources for clean water production and treatment of wastewater, but also containing resources such as essential nutrients for agriculture, energy, heat and water itself. The urban water systems are currently linearly arranged from a systemic perspective. Changing to an urban water cycle could lead to a more sustainable use of these resources.

The circular economy is an economic system that is designed to maximize reusability of products and raw materials and minimize value destruction. This is different than in the current linear system, in which raw materials are converted into products to be destroyed after use. In the current system increasing urbanization leads to the deployment of raw materials for the construction of urban infrastructure such as water supply and drainage systems. In that perspective, the development of self-sufficient neighbourhoods with their own, decentralised water supply add to the image of the circular economy. Currently, in the Dutch water sector itself, several initiatives can be identified around the recovery and reuse of energy and raw materials (such as phosphate) in centralized and decentralized systems.

1.2 Colaborative project 'TKI Loop-closure Cleantech Playground'

This project was implemented within the Top Sector Water. Within the various Top Sectors the government, entrepreneurs and scientists work together in so-called Topconsortia for Knowledge and Innovation (TKI). This TKI project 'Loop-closure Cleantech Playground Amsterdam' is part of the TKI Watertechnology programme and focuses on the water cycle of De Ceuvel in Amsterdam North. The project is a typical TKI Watertechnology collaboration with innovative water technology on the way to market launch in an innovative concept (closure of cycles in practice), and with the business interacting with public organisations and knowledge institutes. This offers advantages for all participating parties.

The company Advanced Waste Water Solutions is interested in the decentral concept and the applicability of loop-closures in the urban environment. Therefore for them this project is a nice demonstration. Metabolic has generated a lot of attention and work with the Cleantech Playground (CTP) and for Waternet the CTP is a very suitable pilot location to investigate a number of pressing questions, such as related to local drinking water production. KWR Water Cycle Research Institute provides knowledge of the water cycle and (laboratory) research facilities. This corresponds with the aim of KWR to bridge science to practice which can result in the practical application of new technology. KWR connects the partners and ensures the scientific component in this TKI project.

In this TKI project innovative Dutch technology is tested in practice. With a successful project the concept and technology can not only be applied in the Netherlands but can be used worldwide. Benefits and advantages will not only be achieved by the end user, but also the environment and the position of the Dutch businesses improves.

1.3 Goal

The primary goal of this project concerning a small-scale pilot in Amsterdam North is to achieve closure of the cycle ‘as much as possible’ by applying innovative concepts and technological solutions. The performance, of in particular water-related technology, was monitored in this TKI project and evaluated in order to demonstrate the applicability in a sustainable circular economy.

1.4 Approach

The project combines innovative high-tech and low-tech installations, involves the (future) users/residents in the building process and the monitoring/evaluation of the concept and the technology and makes optimal use of waste materials. This is an example of a (future) sustainable circular economy. Local energy production (heat/electricity) and wastewater/organic waste treatment with nutrient recovery are applied. Research of the (im)possibilities of local drinking water production, including laws and regulations, is part of the project. There are several possible sources for local drinking water production; from rainwater and grey water, to local surface water. Health risks, sustainability aspects and financial consequences have been extensively investigated. Beside the study of technology performance and development of new solutions for metropolitan areas, human aspects and interactions between users and clean technologies are also studied, to understand how communities can adapt to new systems and changes. Additionally, new business models arising from integrated micro-utilities and institutional barriers are studied. In this way, the Cleantech Playground provides an ideal case for the circular re-development of metropolitan areas, through R&D activities in a real life environment.

1.5 Structure

A description of the Cleantech Playground and practical results of wastewater treatment are given in Chapter 2. This includes the monitoring data from the individual grey water treatment plants, consisting of a settling module and biofilter module, as well as some other achievements of technology, like the applied composting toilets and urine treatment.

The sustainability aspects of centralised and decentralised drinking water production are explored through Life Cycle Assessment (LCA). The results are described in Chapter 3.

In Chapter 4, the health risks of local drinking water production compared to the current centralised drinking water production are considered. This is done using Quantitative Microbial Risk Assessment (QMRA).

Financial considerations of local water treatment and loop-closure compared to the current centralised water chain are provided in Chapter 5. Information about institutional aspects related to local water treatment and local loop-closure, as well as user and stakeholder experiences, including survey results about satisfaction of office renters on De Ceuvel are discussed. At the end of the second project year a symposium about decentralised water and energy solutions was organized. A short summary of the main findings of this symposium is also given in Chapter 5.

Finally in Chapter 6 an overview of the results with the main conclusions of this TKI project, including recommendations, are given.

2 Cleantech Playground and wastewater treatment

2.1 Introduction

As a living lab, the Cleantech Playground (CTP) is a testing ground for innovative clean technologies in the city center that aims to achieve sustainable cycle closure. The concept is realized in Amsterdam North in two adjacent areas: a breeding ground for creative entrepreneurs (De Ceuvel) with 16 offices, a restaurant and a biorefinery system in up-cycled houseboats placed on land; and – not yet realised - a floating residential area for 47 families (Schoonschip). Food production (partly under glass) is combined with decentralised power generation, water treatment and processing of organic waste using innovative technology. The first phase of development of De Ceuvel started in the spring of 2013 on a temporary industrial area where offices are composed of recycled houseboats that are placed on land for a period of ten years. De Ceuvel has been officially opened on June 21st 2014, while Schoonschip is currently in the design phase and construction is projected to start in 2016. This research focuses on the site of De Ceuvel.

2.2 The Cleantech Playground and De Ceuvel

De Ceuvel site in Amsterdam North is a former shipyard that was not used for years. Nowadays completely renovated and insulated houseboats have been installed for a period of 10 years. These houseboats are used as offices for a group of creative initiators. Due to the temporary nature and the highly contaminated soil no underground infrastructure is constructed. The boats have no gas and no sewage system. Instead, each boat has a heat pump, solar panels, a dry composting toilet and a biofilter (small constructed wetland). Offices are connected to the municipal power grid and drinking water supply, although sustainable technologies ensure that the use of these common utilities is significantly lower than in conventional offices. In addition, at the De Ceuvel site a cafe is situated, where urine is collected separately. Centrally located on the grounds of the Cleantech Playground is a composting plant, a struvite reactor and a greenhouse where vegetables are grown potentially using the compost and struvite. The cafe has a conventional sewer connection and water supply. TKI project 'Loop-closure Cleantech Playground' will focus on the water cycle of the offices of De Ceuvel in Amsterdam.

The De Ceuvel project fits very well into the logic of decentralised micro-utilities, as the community aims to achieve 100% renewable energy supply (heating and electricity), 100% on-site wastewater and organic waste treatment and 100% on-site drinking water supply, with the latter not realized due to legislative barriers. The CTP is a showcase location for applied research and R & D. It provides space for testing and showcasing of new technologies that are currently available or already on the market or close to market introduction, but which are still not demand-driven integrated into new urban developments. New about this project is the collaboration between public (research) organisations and private parties for testing various ‘cleantech’ and socio-economic implications, by means of a real-life example in the centre of Amsterdam, which shows how offices and homes can be newly built and rebuilt in a circular city. Although De Ceuvel is a unique and temporary development, there are a wide range of new applications for the used concepts and technologies. The CTP will be a continuous laboratory for testing new technologies for further expansion and opportunities in the circular economy. On De Ceuvel site, alternative solutions for water and energy management are investigated, focused on household and neighbourhood-scale systems with low resource consumption and high nutrient recovery, combined with a strong and dynamic community involvement. The developed and applied small-scale water purification and waste (water) management systems, offer potential for further (inter)national valorisation.

2.3 Grey water treatment and monitoring

The water need of the offices at De Ceuvel has been reduced to a minimum by installing dry composting toilets. Furthermore there are no showers or any other water using machines. Therefore only five litres per capita per day is needed for drinking, food preparation and personal hygiene, compared to the current average of 25 litres in conventional offices and 128 litres in households in The Netherlands (Pieterse-Quirijns *et al.* 2009). The only wastewater from the recycled houseboats on De Ceuvel is grey water from the kitchen sink. Grey water is treated separately. The grey water is treated by a settling module and biofilter including plants before infiltration (Figure 1). Water quality parameters of the incoming and outgoing water are monitored, so that the purification performance can be determined and compliance with the infiltration requirements can be shown.

FIGURE 1 INDIVIDUAL BIOFILTER (2 TANKS) FOR GREY WATER TREATMENT

Systems showed a poorer performance at removing COD and total nitrogen in the first 2 months. This period most likely represents the time needed for the plant roots to grow and the microbiological layer to develop around it. Both are forming the so-called rhizosphere, a necessary ecosystem that enhances nutrient uptake and organic matter biodegradation. After this start-up period, the initially high values of these parameters decreased and stabilized at lower levels.

No such trend is observed regarding phosphorus concentration, indicating that the P-concentration is not affected by the rate of biological growth in the filter (i.e. the biological process used in De Ceuvel systems does not efficiently remove P from the low P-concentration influent). Removal of phosphorous in constructed wetlands mainly takes place through adsorption or binding to the filtration media, or through chemical precipitation, while phosphorus uptake through biological processes remains low (Arias and Brix, 2005).

Preliminary results at De Ceuvel site show no decrease in efficiency of grey water purification in winter, but the removal of suspended solids suffers during the colder winter months.

However, at this early stage it is not yet possible to definitively establish the impact of temperature on the effectiveness of wastewater purification in biofilters. During the summer phase of sampling, biofiltration was downstream of settling systems, located inside the offices. These systems have been removed during fall 2014 (i.e. in between the summer and winter sampling phases), because of (odour) nuisances they were causing. Thus, the removal of these settling systems might have been the origin of the initial higher TSS levels reported in the winter 2014 phase compared to those measured in the summer 2014. However, already in spring 2015 lower TSS levels were detected again. Solids seepage from surrounding soil in the sampling system, due to heavy precipitation during winter or sampling variations of the grab samples might explain the measured variations.

The only regulation that applies to De Ceuvel grey water systems is the 'ground discharge regulation' as the IWT (Individual Wastewater Treatment) effluent is discharged into the ground. Therefore the results of the measured parameters are benchmarked against reference limits (wet besluit lozen buiten inrichtingen, art. 3.6). The effluent of the filters at De Ceuvel is monitored before it is infiltrated in the soil and complies with the standards of IWT systems in The Netherlands (Table 1).

TABLE 1 COMPARISON OF AVERAGE MONITORED INFLUENT AND EFFLUENT QUALITY OF GREY WATER BIOFILTERS AND DUTCH STANDARDS (WET BESLUIT LOZEN BUITEN INRICHTINGEN, ART. 3.6)

	COD (mg/L	Total N (mg/L)	Total P (mg/L)	TSS (mg/L)
Grey water influent	401	14	1.9	43
Grey water effluent	122	6.8	1.6	37
Standards	200	60	6	60

2.4 Composting toilets and processing of excreta

Composting toilets from SunMar are being used in the boats. Through the application of composting toilets on De Ceuvel less wastewater is produced, but the human faeces have to be processed further. The users have to bring the faecal matter from the composting toilet periodically to a central composter (type Joraform). Possibilities for reuse of the compost have been investigated in the TKI project. There is, certainly in the Netherlands, lack of experience in this field. Through a student project (Academic Consultancy Training of Wageningen University) it was examined how dry toilet waste can be handled as safely as possible, at low cost and in a sustainable manner, taking into account technological, legal and social aspects (Bennink *et al.* 2015; Appendix I)[2].

Handling and reuse of human excreta can pose significant health risk, since they can contain high numbers of pathogenic micro-organisms. Prolonged storage and composting of faeces will reduce this pathogen content, but the rate of this process is not well known for specific situations. Storage periods of six months to two years are recommended. Usually, *E. coli,* faecal streptococci or enterococci are used as an indicator of presence of pathogens. However, some pathogens and eggs of worms will survive longer in human faeces than *E. coli*. Accordingly, other and/or more than one indicator species should be considered in order to guarantee a reliable safety standard. Due to the high temperature (> 50°C), low humidity (<25%), extreme pH-values, additives, and a wide variety of non-pathogenic micro-organisms, the composting process may increase the rate at which pathogen numbers decrease. After 11 months composting at De Ceuvel, the level of streptococci was reduced

[2] During six weeks, an interdisciplinary team of six students (FertilOO), participating in the Academic Consultancy Training at Wageningen University, was assigned by KWR to give an advice on reusing valuable components of dry toilet waste originating from CTP de Ceuvel, Amsterdam.

by log 1.9. This does not yet meet the WHO recommendation of log 6 reduction by composting (WHO 2006).

The study suggested a change to vermicomposting at De Ceuvel (Bennink *et al.* 2015). With 'vermicomposting', in which worms are used in the process, the amount of pathogens can be reduced faster, providing a good soil conditioner. For optimum composting the C/N-ratio of the starting material should be about 25. In general, it is advised for human faeces to be composted for at least 2 years and urine should be stored for at least 3 months, with a maximum of 6 months, for safe operation. Urine is in principle a high-grade fertiliser, and can be obtained separate from faeces by means of a urine separating toilet. Vermicomposting and urine separation in the houseboats has not been implemented at De Ceuvel due to some practical limitations.

Practical experience was gained at De Ceuvel site with composting toilets that are used on a daily basis in offices, processing excreta without use of flushing water. However, these toilets are non-separating toilets (i.e. urine is mixed with faeces) and residual liquid in the unit needs to be evaporated. These toilets have either natural or electrical ventilation, which sometimes is not sufficient to evaporate residual liquid, especially for offices that are used intensively. Thus, a solution for this potentially contaminated stream of residual liquid is required, even though flows remain low: most of the offices do not even require toilet liquid drain (drainage pipe was still dry 6 months after the toilet was first in use) while the production of residual liquid is estimated to a maximum of 1 litre per week in the other offices. Based on literature research and advice of composting toilets suppliers, the solution installed on De Ceuvel site for processing the liquid drain of these toilets is evapotranspiration beds. In this bed, built with sand and gravel, residual liquid is contained in the soil within a waterproof plastic liner pond, while roots of specific bushes and plants take up nutrients, the excess liquid is either evaporated or transpirated by the plants. On De Ceuvel site, each of the offices has been provided with this technical solution to prevent any seepage of residual liquid into the ground(water).

There are no Dutch regulations on composting of human waste. However for comparable flows like sewage and livestock manure there is legislation, with the restriction that sewage sludge is not being used as fertiliser in the Netherlands. Use of manure is allowed, but the legislation is focused on the maximum amount of heavy metals and micro-contamination, not on the presence of pathogens. The latter should certainly be considered as a concern when using compost from faeces, because there are clear risks of contamination and infection. Tenants on De Ceuvel are committed and feel responsible for their dry composting toilets, but are generally not well informed of the risks inherent in the processing of human waste (compost). Clear instructions and communication are certainly needed. Moreover, the current composting tumbler is next to the cafe, leaving tenants embarrassed while dropping off their dry faeces. This may be solved by placing the installation in a different location.

Because of the lack of legislation and regulation, and the clear risks, reusing dry faeces is not recommended at this moment. However, by experimenting, it is possible to find out if something works and the CTP is a suitable location to investigate this further.

2.5 Urine and nutrient recovery

One of the largest obstacles to the direct use of urine as a fertiliser is the presence of pharmaceutical micro-pollutants, which are excreted in human urine. Application of urine to crops causes the risk of accumulation of these micro-pollutants in agricultural soils and uptake into edible crops. Phosphate (P) recovery by struvite precipitation excludes the majority of micro-pollutants (Escher *et al.* 2006), but also the majority of available N.

Approximately 100 million tons NH_3-N per year is produced by the energy intensive Haber-Bosch process, accounting for 2% of the world's energy use and resulting in a drastic imbalance of the natural N cycle. It is therefore equally urgent to recycle the reactive N available in waste streams as it is to recover the P. The ratio of N to P in urine is approximately 30:1, but only 1:1 in struvite, so other techniques are needed to supplement N recovery. Clinoptilolite zeolite, purchased from Zeolite Products (Lireweg 5, 7051 HW Varsseveld, Netherlands) and biochar, purchased from Sonnenerde (Oberwarterstraße 100, 7422 Riedlingsdorf, Austria) were used for adsorption experiments (Hammerton 2016). Clinoptilolite zeolite is a naturally occurring volcanic rock, whose chemical properties make it able to interact electrostatically with NH_4^+. Biochar is an alternative to zeolite, produced out of organic material. Both zeolite and biochar have application as soil conditioners, as their porosity results in improved water retention. Furthermore, biochar addition to soils is a possible carbon sequestration technique. However, the use of these materials also is also risking the uptake of pharmaceutical micro-pollutants present in urine.

Pure urine from a waterless urinal at Café De Ceuvel was stored in two 100 L buffer tanks. Nutrients were recovered from the urine using struvite ($MgNH_4PO_4.6H_2O$) precipitation and adsorbent materials (clinoptilolite zeolite and biochar) to generate fertilisers that were used for production of tomatoes. Urine was pumped from the second buffer tank to the struvite reactor after several days. Magnesium chloride was used for struvite precipitation.

In January 2015, struvite was legalized as a fertiliser in the Netherlands in an amendment to the "Uitvoeringsbesluit Meststoffenwet", with the restriction that the required micro-pollutant limits for fertilisers are not exceeded. In this study pharmaceutical micro-pollutants (carbamazepine (> 98%), (±)-propranolol-HCl (≥ 99%), diclofenac sodium (> 98%), sulfamethoxazole (> 98%) and ibuprofen (> 98%)), obtained from Sigma Aldrich, were added to the urine stream based on toxic potency and molar predicted urine concentrations (PUC), calculated by Escher *et al.* (2006). Subsequently struvite crystallization was carried out in a column reactor, using 25 L spiked urine and 32% $MgCl_2$(aq.) in volumes determined by the urine P concentration in Mg:P ratios shown in Table 2. For N sorption experiments, subsequently 300 g zeolite or biochar was added to the reactor.

TABLE 2 EXPERIMENTAL CONDITIONS FOR FERTILISER PREPARATION AND CROP TRIAL (HAMMERTON 2016)

Pot	Fertiliser (*urine derived)	Description	Mg:P ratio in urine
1	Struvite*	Struvite crystalisation	1.2:1
2	SZM*	Struvite crystalisation and N adsorption to Zeolite Material	1.2:1
3	SB*	Struvite crystalisation and N adsorption to Biochar	5:1
4	NPK Benchmark	Artificial fertiliser (N:P:K)	-
5	Zeolite+N*	N adsorption to zeolite	0:1
6	Biochar+N*	N adsorption to biochar	0:1
7	Zeolite control	Not in contact with urine/No added nutrients	-
8	Biochar control	Not in contact with urine/No added nutrients	-
9	Negative control	Not in contact with urine/No added nutrients	-

FIGURE 2 CROP TRIAL AFTER 60 DAYS GROWTH IN THE GREENHOUSE (SEE TABLE 2 FOR DESCRIPTION OF FERTILISER STREAMS)

Each mixture was aerated for 2 hours, during which struvite precipitation occurred and N was taken up by adsorbent materials. The reactor was then drained, the solid fertiliser material collected on a filter, washed with water and air-dried. Samples of the influent and effluent urine were taken for N, P and micro-pollutant analysis. Five batches of each fertiliser stream were prepared using this method. The struvite precipitated from spiked urine recovered approximately 96% P and 6% N, which increased to 98% P and approximately 10% N, when combined with sorbent materials.

Urine-derived fertilisers were tested in a crop trial with Tiny Tim tomato plants, in nutrient poor, sandy soil, to which fertilisers were added and balanced by P content (6.37 g P/plant). To allow comparison between struvite based fertilisers, control fertilisers and a benchmark NPK fertiliser, 9 different experimental conditions were tested (Table 2). The plant growth experiments with the 9 fertiliser streams were repeated 3 times (n=3) to enable statistical analysis (Figure 2). The nutrient bioavailability of struvite-sorbent fertilisers was shown to be high. Plants grown in sorbent fertilisers in the absence of struvite, however, were shown to be nutrient deficient (Figure 3).

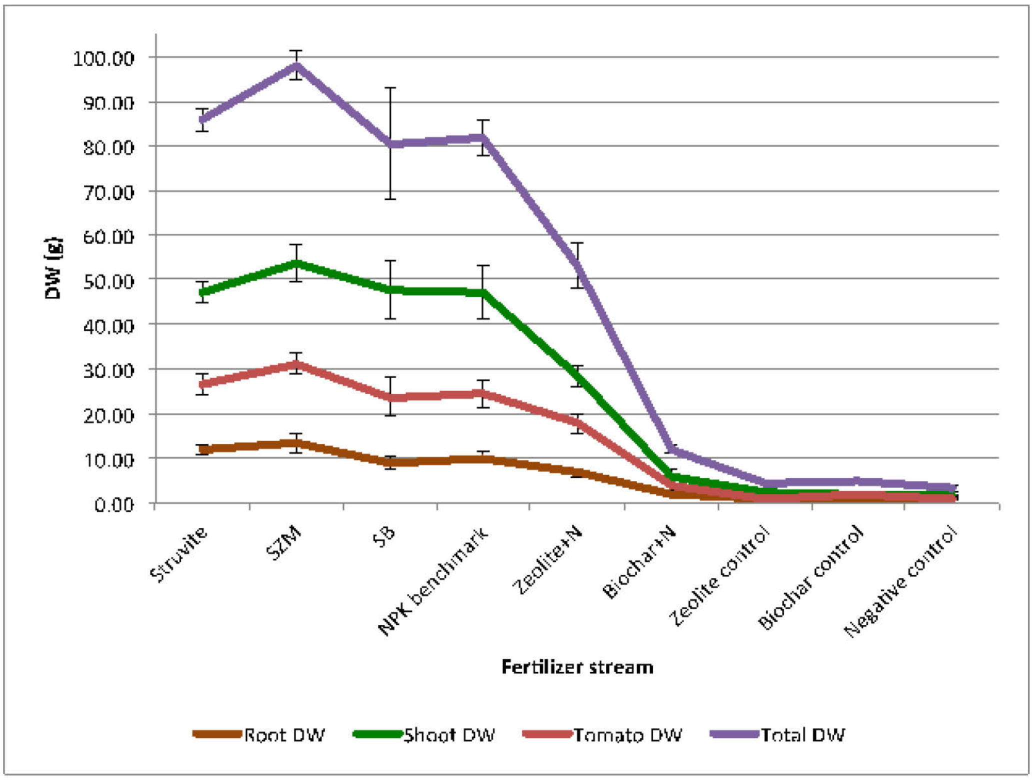


FIGURE 3 TOMATO PLANT ROOT, SHOOT AND TOMATO FRUIT DRY WEIGHT (DW) FOR PLANTS GROWN IN EACH FERTILISER STREAM (SEE TABLE 2 FOR DESCRIPTION OF FERTILISER STREAMS)

The concentration of pharmaceuticals in tomato biomass was below detection limits (0.02 mg/kg). These levels were far below the acceptable daily intake (ADI), which is 1% of the minimum therapeutic dose (Hammerton 2016). It is therefore possible that tomatoes produced using urine-derived struvite-sorbent fertilisers are safe for human consumption. However, although no bio-accumulation was detected in the tomato biomass, this does not preclude bio-accumulation in other parts of the plant, for example the roots or leaves, which were not tested. Because nutrients and other molecules are taken up from soil by the roots, micro-pollutants might accumulate in root biomass. As humans do not generally consume tomato plant roots and leaves, this is unlikely to directly affect human health. However it may be necessary to carry out further research in order to determine the indirect risk of using contaminated plant biomass as a feedstock for other purposes, such as compost or animal feed. Further investigation should also be carried out into struvite-sorbent fertilisers for root crops, such as carrots or radishes, and leafy vegetables, such as lettuces. Besides a much larger crop trial, also a broader range of pharmaceuticals are necessary to test the robustness of these preliminary experiments. The nutrients in biochar-based fertiliser were shown to be less available than zeolite-based fertilisers in the short-term, but could become more available after degradation of biochar. The long-term effects of using contaminated urine-derived struvite-sorbent fertilisers on soil quality should therefore also be investigated.

3 LCA: decentralised versus centralised drinking water production

3.1 Introduction

Nowadays sustainability issues become more and more important in making decisions. Sustainability of scenarios or processes is usually hard to compare. This is a result of the fact that each scenario has its advantages, but the benefits cannot be related to each other one to one. E.g. one scenario may result in the use of less chemicals, as in another scenario the energy demand is significantly reduced. Furthermore, it is also important to include a cradle-to-grave-approach (Figure 4), in order to compare equally. Life cycle assessment (LCA) is a tool that helps to compare sustainability of different scenarios.

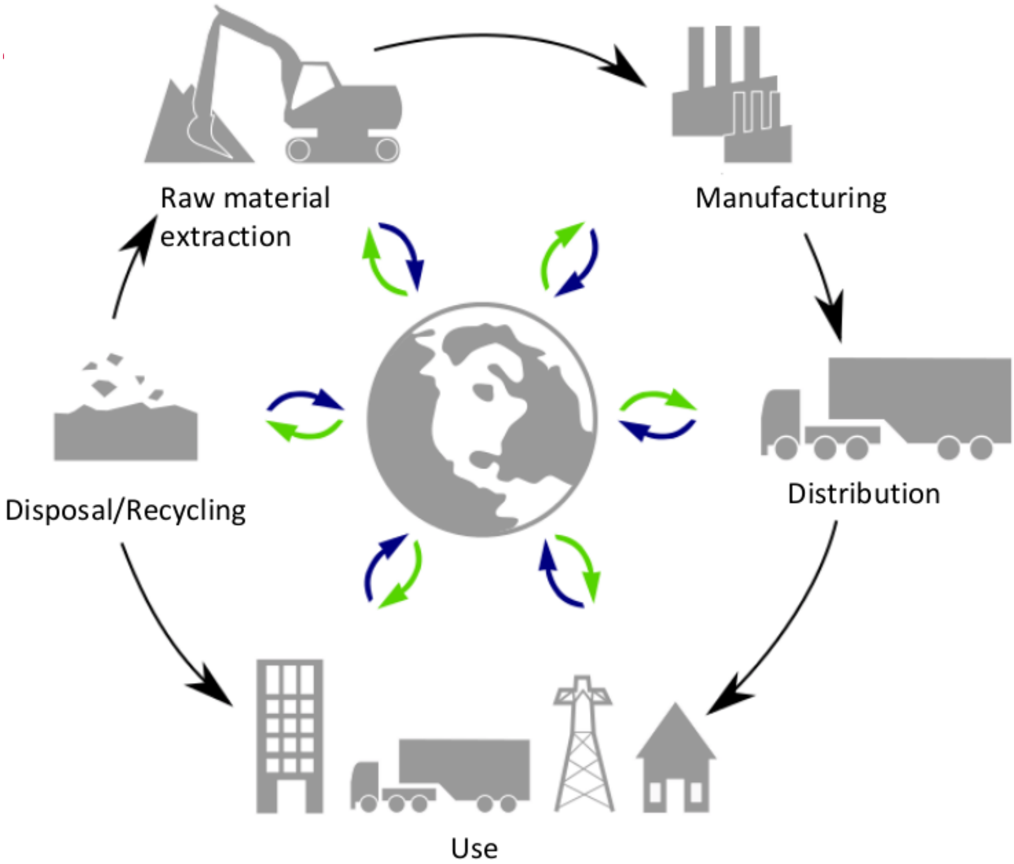


FIGURE 4 ILLUSTRATION OF A CRADLE TO GRAVE APPROACH

To conduct an LCA study it is important to follow certain steps, which are specified in Figure 5. The scheme in Figure 5 shows clearly that the steps interact with each other. Nevertheless in all cases, it is important to start with the goal and scope definition. The environmental impact is modelled and expressed in Ecopoints effect. In this analyses1.000 Ecopoints correspond to the total environmental impact of one Western European person per year.

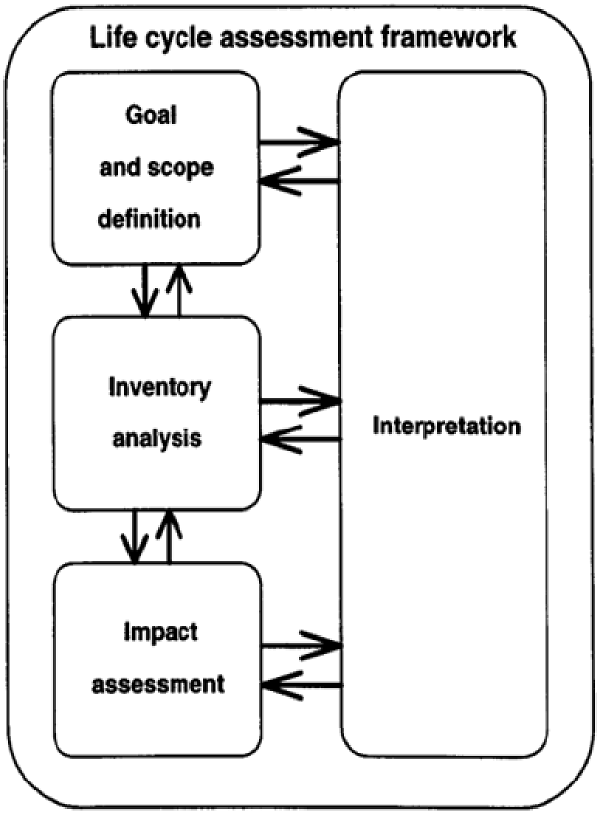


FIGURE 5 A SCHEMATIC OVERVIEW OF THE STEPS INVOLVED IN A LIFE CYCLE ASSESMENT ANALYSES.

For the discussion regarding centralised or decentralised drinking water production, it is also important to include sustainability, besides the social and economic reasoning. In the literature some studies were found, that compare the decentralised and centralised drinking water production, in which the scenario for the production of decentralised drinking water was based on the use of bottled water (Dettore 2009; Fantin et al. 2014, Vanderheyden and Aerts 2014). The intention at De Ceuvel is to produce the drinking water on site, and therefore a new LCA-study to compare centralised drinking water to decentralised drinking water production on site was necessary.

3.2 Approach and methods

3.2.1 Goal

The goal of this LCA study was to compare the sustainability of centralised and decentralised drinking water production, specific for the operational aspects. The drinking water productionplant at Weesperkarspel (Waternet, Amsterdam) was used as a model for a centralised drinking water production, and the local water treatment system designed for De Ceuvel was used as model for the decentralised potable water production scenario. The goal of both systems is to produce drinking water according to Dutch quality standards.

3.2.2 System boundary

As in both scenarios the function is to produce drinking water, the delivery of 1 m^3 safe potable drinking water was considered as the functional unit.

Functional unit:	delivery of 1m³ drinking water

For De Ceuvel a usage of a few m³ per day of drinking water is expected. In case De Ceuvel is enlarged, the potable water requirements will increase. Nevertheless, the impact of each parameter is in the same order of magnitude, similar for each produced m³ potable water. Therefore, the comparison between centralised and decentralised drinking water production, which is based on the production of 1 m³ drinking water, remains equal.

The total requirements for the production of drinking water in both scenarios were considered. The schemes of included units are given in the "required data" paragraph.
As only the effect of operational sustainability was taken into account, only consumables of one year were included. Therefore, the pipes, tanks and housing, for instance, were not included in the study.

3.2.3 Inventory data

For the analyses of this LCA study the SimaPro 8 software was used, combined with the EcoInvent 3.0 database. For calculations the ReCiPe Endpoint € V1.10 / Europe ReCiPe E/A was applied. If no data specific for the Netherlands were available in the EcoInvent 3.0 database, the following order was applied: Rer (rest of Europe), Ch (Switzerland) and then RoW (Rest of the world).

Centralised drinking water production at Weesperkarspel
Centralised drinking water production at Weesperkarspel consists of two main treatment processes. It is first pretreated at Loenderveen, according to the scheme presented as Figure 6, thereafter it is transported to Weesperkarspel. At Weesperkarspel other processes are applied to complete drinking water production. These processes are presented in Figure 7.

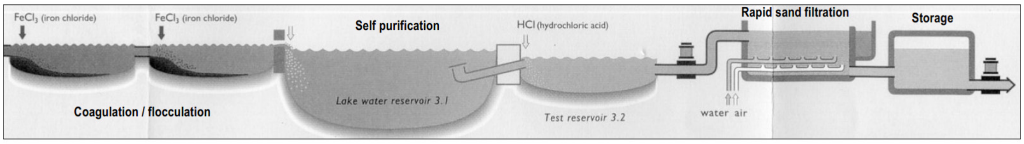


FIGURE 6 SCHEMATIC OVERVIEW OF PRETREATMENT AT LOENDERVEEN

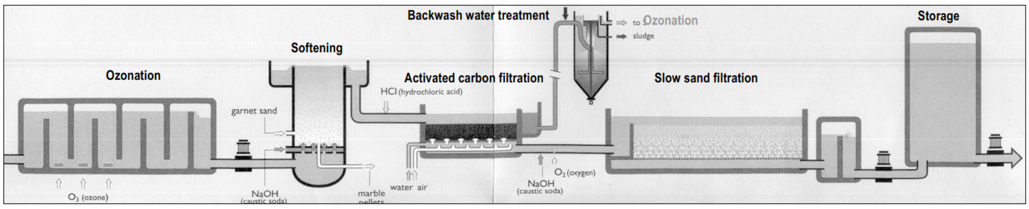


FIGURE 7 SCHEMATIC OVERVIEW OF DRINKING WATER PRODUCTION AT WEESPERKARSPEL

The data used for LCA analyses of the centralised drinking water treatment as performed at Weesperkarspel are presented in Table 3. It includes both the original data and the normalised values.

TABLE 3 STARTING DATA FOR LCA ANALYSES OF CENTRALISED DRINKING WATER TREATMENT, DATA IS ADAPTED FROM BARRIOS ET AL. (2004)

Process steps and parameters	Original data	Normalised value*
1. Raw water intake		
Power consumption raw water intake of canal	322,000 kWh/year	0.011552398 kWh/m^3
2. Coagulation and settling		
Usage of $FeCl_3$ (100%)	1,102,688 kg/year	0.03846 kg/m^3
Transport $FeCl_3$ from Ibbenburen	220 km	0.00846 tkm/m^3
Production dry sludge	1,000 ton/year	0.034878 kg/m^3
Transport dry sludge	37 km	0.00129 tkm/m^3
3. Lake reservoir		
Usage HCl (100%)	262,626 kg/year	0.00915 kg/m^3
Transport HCl from Ibbenburen	220 km	0.002015 tkm/m^3
4. Pump from lake to sand filtration		
Energy consumption pump	640,000 kWh/year	0.02232 kWh/m^3
5. Sand filtration		
Usage H_3PO_4 (100%)	184 kg/year	0.006404 g/m^3
Transport H_3PO_4 from Ibbenburen	220 km	1.408*10^{-6} tkm/m^3
Water usage backwash	78,500 m^3/year	0.002737 m^3/m^3
Production of sludge	393 ton/year	0.01369 kg/m^3
Transport of sludge	37 km	0.000507 tkm/m^3
6. Transport to Weesperkarspel		
Energy consumption pump	800,000 kWh/year	0.027903 kWh/m^3
7. Ozonation		
Power consumption O_3 production	1,408,240 kWh/year	0.050523 kWh/m^3
8. Softening		
Power consumption	4,451,940 kWh/year	0.1597 kWh/m^3
Sand usage	246 ton/year	0.008825 kg/m^3
Sand transport by boat	22,000 km	0.1941 tkm/m^3
Sand transport by truck	200 km	0.001765 tkm/m^3
NaOH usage (100%)	1,179 ton/year	0.042297 kg/m^3
NaOH transport from Brussel	220 km	0.009305 tkm/m^3
Calcium carbonate production	2,393 ton/year	0.08585 kg/m^3
Calcium carbonate transport to IJmuiden	45 km	0.00386 tkm/m^3
Usage of HCl (100%)	153.636 kg/year	0.005512 kg/m^3
Transport HCl from Ibbenburen	220 km	0.00115 tkm/m^3
NaCl usage (for ionexchange)	2.450 kg/year	8.788*10^{-5} kg/m^3
Transport NaCl	50km	4.3949*10^{-6} tkm/m^3
9. Biological activated carbon filtration		
Energy consumption (backwash)	158.060 kWh/year	0.00567 kWh/m^3
Usage activated carbon	123.600 kg/year	0.004434 kg/m^3
Transport activated carbon from Hembrug.	30 km	0.000133 tkm/m^3
Steam usage	1.020.600 kg/year	0.0366 kg/m^3
HCl usage (100%)	7.740 kg/year	0.000277 kg/m^3
Transport HCl from Ibbenburen	220 km	5.83*10^{-5} tkm/m^3
10. Sand filtration (slow)		
Energy consumption	672.640 kWh/year	0.02413 kWh/m^3
NaOH usage (100%)	209 ton/year	0.00748 kg/m^3
Transport NaOH Brussel	220 km	0.001645 tkm/m^3
Sand usage	450 ton/year	0.01612 kg/m^3
Transport sand	100 km	0.001612 tkm/m^3
Sand discharge	450 ton year	0.01612 kg/m^3
Transport sand discharge	100 km	0.001612 tkm/m^3
Usage of liquid oxygen	87 ton/year	0.00312 kg/m^3
Transport liquid usage	50 km	0.000156 tkm/m^3

**unit tkm means ton*km (10 tkm is equivalent to the transport of 10 ton over 1 km or 0.1 ton over 100 km or any equivalent combination).*

Decentralised drinking water production

As there is no decentralised drinking water production at De Ceuvel, a new process design was proposed. This design of decentralised drinking water production needs to be realistic, and therefore the raw intake water (local canal water) and the small area available were taken into account. The suggested decentralised drinking water production treatment scheme is presented in Figure 8.

FIGURE 8 SCHEMATIC OVERVIEW OF SUGGESTED DECENTRALISED DRINKING WATER TREATMENT AT DE CEUVEL, FROM LOCAL SURFACE WATER TO DRINKING WATER

In some of the steps presented in Figure 8 water is lost. The recovery of each separate step is summarized in Table 4.

TABLE 4 RECOVERY OF EVERY PROCESS STEP IN DECENTRALISED DRINKING WATER TREATMENT

Process step	Recovery (%)	Factor compared to produced drinking water
1. Raw water intake	100	1.568
2. Ultrafiltration	85	1.568
3. Nanofiltration	75	1.33
4. UV	100	1
5. Remineralization	100	1

As this scenario at De Ceuvel is not applied yet, it is not known from which company the chemicals will be ordered. For this study it was assumed that the chemicals come from the same company as for the centralised drinking water production at Weesperkarspel. The data used for LCA analyses of the decentralised drinking water treatment are presented in Table 5. It includes both the original data and the normalised values.

To avoid clogging of the membrane, wash steps and chemicals are required. For ultrafiltration chlorine and acetic acid are used, for nanofiltration HCl and NaOH. The assumptions made to calculate the chemical consumption per production of 1 m^3 potable water are summarized in Table 6.

TABLE 5 STARTING DATA FOR LCA ANALYSES OF DECENTRALISED DRINKING WATER PRODUCTION.

Process steps and parameters*	Original data	Normalised value	Source
1. Raw water intake			
Energy consumption pump	*4.6W/mwh per m³*		*HH and EC*
Height to pump	*5 m*		*Assumption*
Energy consumption pump	*0.023 kWh/m³*		*calculation*
Energy consumption pump	0.03607 kWh/m³	0.03607 kWh/m³	calculated
2. Ultrafiltration			
Energy consumption at effluent installation	*0.1 kWh/m³*		*HH and EC*
Total energy consumption at produced water	0.1333 kWh/m³	0.1333 kWh/m³	calculated
Total dissolved solids in raw water	*8.9 g/m³*		*Data-ICT-Dienst Rijkswaterstaat*
Total dissolved solids discharge	13.96 g/m³		Calculated
CEB1 usage (p.w.) (chlorine)	1.2254 g/m³		HH and EC
Transport CEB1	220 km	0.0002696 tkm/m³	(Barrios et al. 2004)
CEB2 usage (Acetic acid)	0.0098 g/m³		HH and EC
Transport CEB2	220 km	2.15*10⁻⁶ tkm/m³	
Colloidal parts in raw water	*0.0089 mg/m³*		*Data-ICT-Dienst Rijkswaterstaat*
Colloidal parts discharged	0.01396 mg/m³		calculated
Pump energy brine	0.0667 kWh/m³		HH and EC
Steel (membrane)	0.00045 kg/m³		(Bonton *et al.* 2012)
PVC (membrane)	0.00004 kg/m³		(Bonton et al. 2012)
3. Nanofiltration			
Energy consumption E.I.	0.6 kWh/m³		HH and EC
Antiscalant usage. E.I. (organophosphorus)	0.004 mg/m³		HH and EC
Transport antiscalant	220 km	8.8*10⁻¹⁰ tkm/m³	(Barrios et al. 2004)
Salt in raw water (NaCl)	3.6 mg/m³		Data-ICT-Dienst Rijkswaterstaat
Salts discharged	5.64 mg/m³		calculated
Pump energy	0.05 kWh/m³		HH and EC
Acid usage (HCl)	0.0312 g/m³		HH and EC
Transport acid	220km	6.86*10⁻⁶ tkm/m³	(Barrios et al. 2004)
Caustic usage (NaOH)	0.0342 g/m³		
Caustric transport	220 km	7.53*10⁻⁶ tkm/m³	(Barrios et al. 2004)
Steel (membrane)	0.00045 kg/m³		(Bonton et al. 2012)
PVC (membrane)	0.00004 kg/m³		(Bonton et al. 2012)
Inert material wasted	5.64 mg/m³		calculated
4. UV			
Energy consumption	0.1 kWh/m³		HH and EC
Replace UV-lamp	*Once a year*		*(Barrios et al. 2004)*
Mercury in UV-lamp	5 mg/lamp	0.00456 mg/m³	http://www.negativeiongenerators.com/UV-C_spectrum.html
Transport mercury	220 km		(Barrios et al. 2004)
5. Remineralization			
$CaCO_3$ usage	0.1 mg/m³		HH and EC
Transport $CaCO_3$	220km	2.2*10⁻⁸ tkm/m³	(Barrios et al. 2004)
Acid usage	0.024 mg/m³		HH and EC
Transport acid	220 km	5.28*10⁻⁹ tkm/m³	(Barrios et al. 2004)

*Data with source HH and EC is derived from personal communications with Hans Huiting and Emile Cornelissen (KWR). Data-ICT-Dienst Rijkswaterstaat measurements are from Amsterdam IJtunnel (km 25) of period 2010-2014. *E.I.: effluent (from) installation: this value is compared to the water flowing out of the installation; p.w.: produced water: this value corresponds to the finally produced potable water.*

TABLE 6 ASSUMPTIONS REGARDING BACKWASH AGENTS FOR ULTRA AND NANO FILTRATION.

UF, CEB1 (chlorine)	
UF backwash	48 times/day
Backwash with CEB1	0.5 times/day
Usage of CEB1 in E.I.	500 g/m^3
UF, CEB2 (acetic acid)	
How often UF backwashed	0.1 times/day
CEB2 usage	2%
NF, acid (HCl)	
Required pH	2
HCl concentration	364.3 g/m^3
Amount of backwash steps	6 times/year
Recovery	75%
NF, caustic (NaOH)	
Required pH	12
HCl concentration	399.97 g/m^3
Amount of backwash steps	6 times/year
Recovery	75%

The assumptions were based on knowledge of Hans Huiting and Emile Cornelissen (KWR). E.I.: effluent (from) installation: this value is compared to the water flowing out of the installation.

3.3 Results

3.3.1 Centralised drinking water production

Table 7 summarizes the results from the LCA model of the centralised drinking water production scenario in both Ecopoints and percentages. The production of 1m^3 potable water at Weesperkarspel costs 0.0762 Ecopoints. The pretreatment accounts for 1/3 of the total sustainability impact. For coagulation the highest Ecopoint impact is caused by usage of iron chloride. The consumption of iron chloride corresponds to 0.0154 Ecopoints, which is 20% of the total environmental impact. For the treatment process at Weesperkarspel the process-step softening has the highest environmental impact, responsible for 0.0319 Ecopoints, which is 42% of the total impact for the delivery of drinking water by the centralised treatment process. The high environmental impact of softening is mainly caused by the usage of sodium hydroxide (0.0143 Ecopoint) and electricity (0.0167 Ecopoints). Consumption of chemicals and electricity for the softening process step has an environment impact of respectively 19 and 22% for the production of potable drinking water by centralised drinking water production system.

The environmental impact is separated in 17 criteria categories. From the results it can be concluded that the categories human toxicity and fossil depletion are most negatively affected by the centralised production of drinking water (Figure 9).

TABLE 7 ENVIRONMENTAL IMPACT OF PROCESS STEPS FOR THE CENTRALISED PRODUCTION OF POTABLE WATER

	Process	Ecopoints (Pt)	Percentage (%)
	Total	**0.0762**	**100**
	Water intake	0.00121	1.59
	Coagulation	0.0201	26.3
Pre-treatment	Lake reservoir	0.00281	3.69
	Pump to sand filtration	0.00233	3.06
	Rapid sand filtration	0.000186	0.24
	Pump to Weesperkarspel	0.00292	3.83
	Total pre-treatment	**0.0295**	**38.8**
	Ozone treatment	0.00528	6.94
Weesperkarspel	Softening	0.0319	41.9
	Activated carbon	0.00388	5.09
	Slow sand filtration	0.00561	7.36
	Total treatment Weesperkarspel	**0.0466**	**61.2**

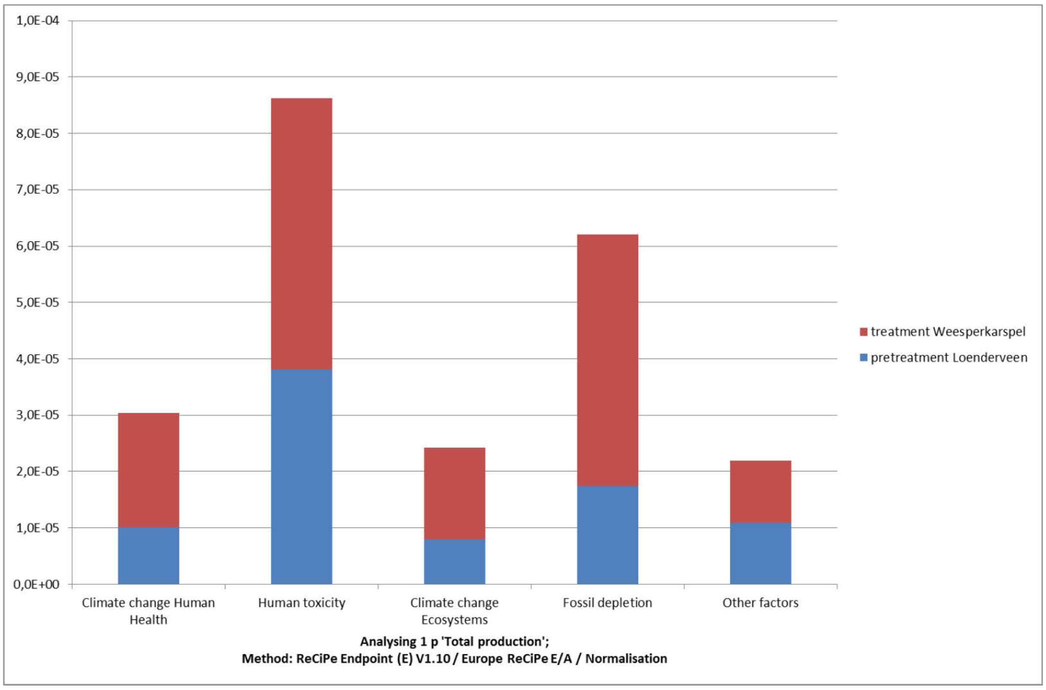


FIGURE 9 NORMALISED VALUES PER IMPACT CATEGORY FOR THE CENTRALISED DRINKING WATER PRODUCTION

3.3.2 Decentralised drinking water production

The decentralised drinking water production as proposed in this study, will cost 0.104 Ecopoints for the production of 1m^3 potable water (Table 8). Within this treatment process, ultra and nanofiltration have the highest environmental impact. In both processes this is caused by the high consumption of electricity, which accounts for 20 and 60%, for respectively ultrafiltration and nanofiltration.

TABLE 8 ENVIRONMENTAL IMPACT OF PROCESS STEPS FOR THE DECENTRALISED PRODUCTION OF POTABLE WATER

Process	Ecopoints (Pt)	Percentage (%)
Total	0.104	100
Raw water intake	0.00377	3.62
Ultrafiltration	0.0217	20.8
Nanofiltration	0.0682	65.5
UV	0.0105	10
Remineralization	$3.93*10^{-9}$	$3.77*10^{-6}$

The impact of decentralised drinking water production was also analysed per category. Four main category contributors were noticed: climate change (human health), human toxicity, climate change (ecosystems) and fossil depletion (Figure 10).

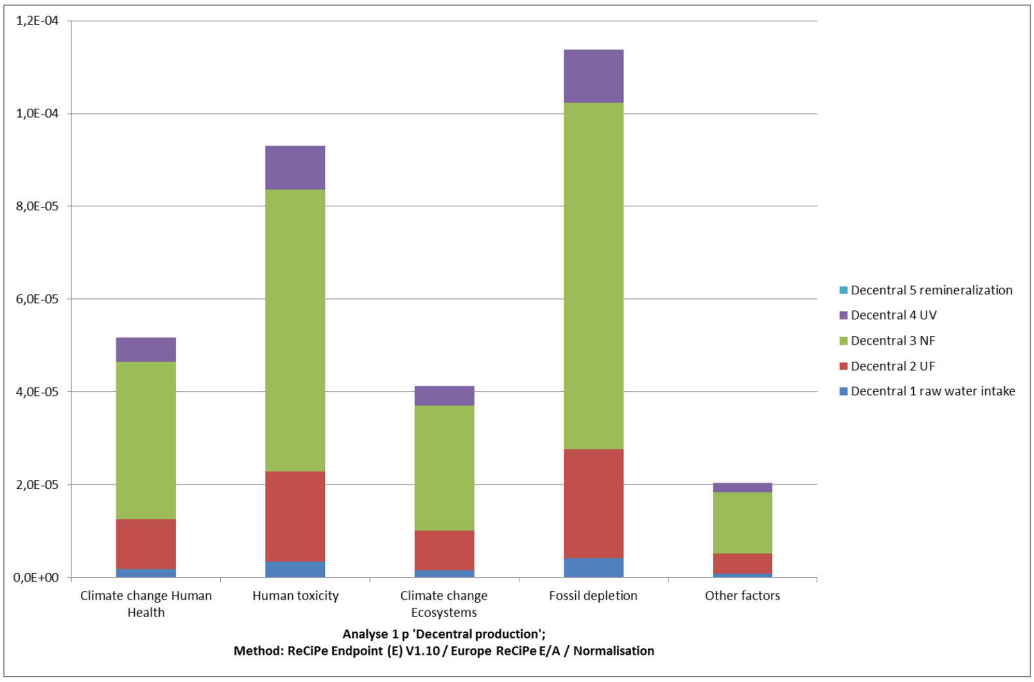


FIGURE 10 NORMALISED VALUES PER IMPACT CATEGORY FOR THE DECENTRALISED DRINKING WATER PRODUCTION

3.3.3 Comparison of the two scenario's

Subsequently it was of interest to compare the centralised and decentralised drinking water production scenarios. Table 9 shows that the impact of the decentralised scenario was higher (0.104 Ecopoints) compared to the centralised scenario (0.0762 Ecopoints). In theory implementation of the centralised treatment process at De Ceuvel, would result in identical environmental impact per 1m^3 drinking water production from surface water. The local water quality and the limited space at De Ceuvel drives the need for other and more compact treatment technologies, which have a higher environmental impact.

From the 17 criteria categories in which the environmental impact is calculated there appeared four main category contributors (Figure 11). For most of the categories the centralised scenario scores better, thus has a lower environmental impact, then the decentralised scenario. For three categories, particulate matter, natural land transformation and metal depletion, a minor higher impact is noticed for the centralised scenario.

TABLE 9 THE COMPARISON OF ECOPOINTS FOR THE PRODUCTION OF 1M3 FOR EACH SCENARIO

	Single point
Centralised	0.0762
Decentralised	0.104

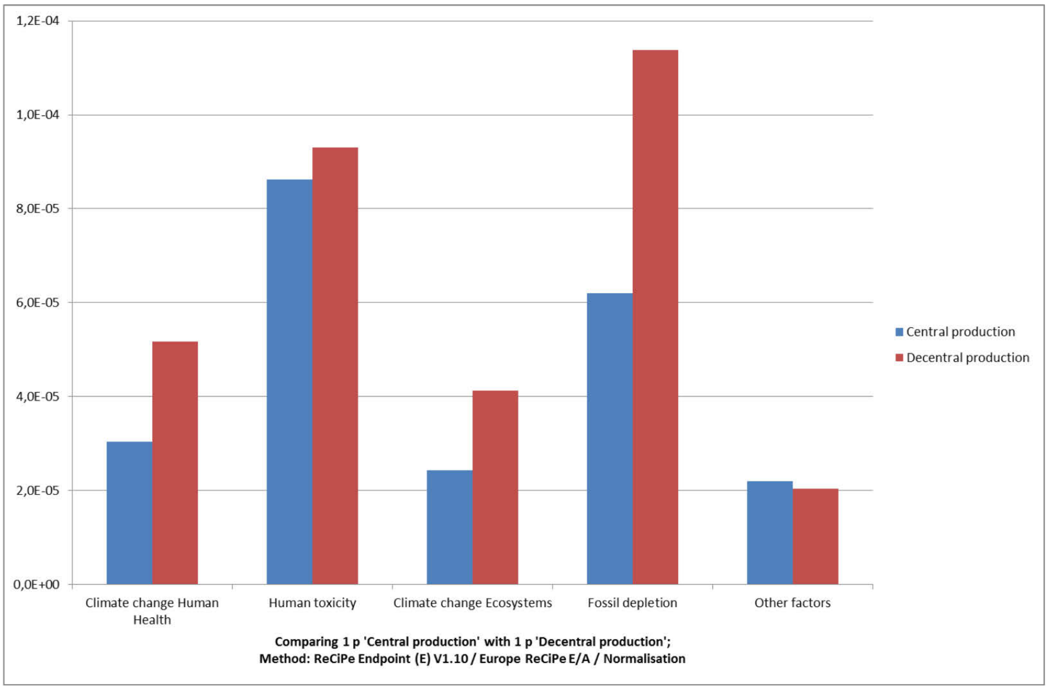


FIGURE 11 THE COMPARISON OF ENVIRONMENTAL IMPACT OF CENTRALISED AND DECENTRALISED DRINKING WATER PRODUCTION

3.3.4 Sensitivity analyses

LCA is a tool to show and discuss sustainability issues. However, the outcome of the study is strongly determined by choices of borders and parameters; i.e. to or not to include the distribution network. To show the impact of these type of choices a parameter sensitivity analyses was performed regarding the distribution network and energy source. Furthermore, also the parameters with the highest impact within the centralised or decentralised scenario were investigated for its effects on the total impact within this LCA study.

Distribution network

It was hypothesized that the distribution network required for both scenarios, would have a relatively higher impact for the centralised than for the decentralised scenario. Though this parameter is not a “consumable within a year”, so an additional scan for its impact was performed. The distribution network in Amsterdam is 3100 kilometre (Alex van der Helm (Waternet)). However, not all of it corresponds to the production of Weesperkarspel, as also water from Leiduin is distributed by this system. For now, no distinction has been made, and all the network was accounted for the production at Weesperkarspel. Assuming a life cycle of the network of 35 years. A distribution network of 0.003178 meter corresponds to the production of 1m^3 potable water production. Database EcoInvent 3.0 data was used to model a general distribution network for the supply of water.

For decentralised drinking water the same data from the database was used. Here a total network of 500 meter was assumed (and Schoonschip is included in this scenario), which corresponds to 0.013 meter network per 1m^3 potable water production. Due to the low water use at De Ceuvel, the distribution network transports 20 times less water than the conventional system. Still the length and diameter of the distribution system are similar, since they are designed to provide sufficient water when opening a tap. In addition, the population at De Ceuvel is less dense than the average in Amsterdam, where flats result in high water consumption in a small area, and therefore relatively less distribution network. The distribution network for the centralised scenario accounts for 37% of the environmental impact, for de decentralised scenario it is 64%.

TABLE 10 PARAMETER SENSITIVITY ANALYSES TO THE INCLUSION OF A DISTRIBUTION NETWORK

	Original study	Including distribution network	Including half of distribution network
Centralised	0.0762	0.122	0,0991
Decentralised	0.104	0.291	0,198

Usage of energy

The parameters sensitivity analysis reveals that energy consumption has a major environmental impact in both concepts. Therefore, several other, more green, energy sources were modelled and the results are summarized in Table 11. Solar energy was not included in this analysis, as no data was present in EcoInvent 3.0.

TABLE 11 PARAMETER SENSITIVITY ANALYSES FOR ENERGY SOURCE

Electricity source	Decentralised concept	Centralised concept
Electricity medium voltage	0.104	0.0762
Electricity high voltage	0.101	0.0753
Turbine, on shore (high voltage)	0.00948	0.0478
Production mix (high voltage)	0.0838	0.0701
Nuclear energy (high voltage)	0.0137	0.0491

From the results as presented in Table 11 it can be concluded that the origin of electricity strongly determines the total environmental impact. For a sustainable solution it is therefore of great importance to select a green energy source, but as long as there is a shortage of green energy, choosing technologies with minimal energy usage is the most sustainable option. Both with the general medium and high voltage, as well as with the mixed electricity production, the centralised drinking water production concept has a lower impact. However, when a more sustainable energy source is chosen (on shore turbine), the decentralised concept from this study proved significantly better. The future prediction about the origin and therefore sustainability of electricity is therefore a major parameter in the selection of water treatment technologies. This counts for both centralised and decentralised drinking water production.

Centralised scenario

The parameter sensitivity analysis revealed that chemicals and energy consumption have the highest environmental impact in the centralised scenario. The results from the analyses of a half lower or twice as much drinking water consumption are presented in Table 12. Especially the electricity required for the softening process is a very sensitive parameter, which also is true for the caustic consumption. An improvement in the softening step, such as the currently suggested reuse of pure calcite for instance, will reduce the environmental impact of the potable water production at Weesperkarspel, mainly because of avoided transport.

TABLE 12 PARAMETER SENSITIVITY ANALYSES FOR SCENARIO "CENTRALISED DRINKING WATER PRODUCTION"

	Half lower	Basis	Double more
Iron for coagulation	0.0684	0.0762	0.0912
Electricity for ozon	0.0735	0.0762	0.0813
NaOH for softening	0.0690	0.0762	0.0902
Electricity for softening	0.0678	0.0762	0.0908

Decentralised scenario

It is important to mention some of the data which is included and excluded in the analyses. The main environmental contributing parameter is the usage of electricity. The variation in electricity consumption will therefore have a high impact. Doubling the electricity consumption will increase the environmental impact from 0.104 to 0.197. Furthermore, parameters specific for the membranes and UV-lamp are rough estimates, and therefore analysed for its sensitivity as well. Doubling the consumption of these materials will hardly increase the impact. Other compounds were not studied within the scenario, as the basic contribution to the environmental impact is low. It was decided to include the replacement of membranes once a year, although this might not be necessary. In one study the requirements of steel and PVC was noted, however, this is not a complete representation of membranes. Therefore, the environmental impact might even be higher. However, the impact of steel and PVC is very low (together only 0.03%). However, if a high-impact material was overlooked, the impact might be underestimated in this study.

TABLE 13 PARAMETER SENSITIVITY ANALYSES FOR SCENARIO "DECENTRALISED DRINKING WATER PRODUCTION"

	Half lower	Basis	Double more
Electricity usage	0.0571	0.104	0.197
Steel (membrane)	0.104	0.104	0.105
PVC (membrane)	0.104	0.104	0.104
Mercury (UV-lamp)	0.104	0.104	0.104

Conclusions

The question what concept (decentralised or centralised) is more sustainable is strongly determined by the choice of treatment concept. Decentralised systems are only feasible with scalable, highly automated, easily operated treatment processes. In this case (and in general) these processes require more energy per m^3 produced water than large scale centralised systems. Improvements in energy demand or (green) energy supply can be implemented both at centralised and decentralised scale and as such there is no difference in environmental impact. The analysis provided insight in the most relevant factors for environmental impact. Decentralised systems could result in environmental benefits in specific situations, which could be studied further:

- When a cleaner, local water source (rain water or ground water) is available that requires less treatment.
- When centralised distribution systems have a high leakage rate.
- When synergistic effects are achieved, e.g. rainwater harvesting as a water source and to buffer water, reducing storm water infrastructure and treatment.
- When no distribution network is needed, so a source and treatment per connection
- When there is a local surplus of green energy.
- When the location is remote, far from centralised supply (reducing water transport energy).

The analysis assessed the environmental impact per m^3 of drinking water. The fact that less drinking water is used at De Ceuvel does reduce the environmental impact of operations.

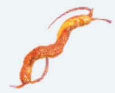
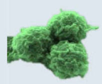
The impact of infrastructure , especially distribution, is not affected by the use, since the momentary demand when opening a tap determines the design of this infrastructure. Nevertheless, the overall environmental impact of drinking water production is relatively low, since the total environmental impact of one Western European person corresponds to thousand Ecopoints per year.

4 Safe drinking water supply

4.1 Introduction to drinking water safety

Water can contain microbial, chemical and radiological contaminants that can cause adverse health effects when consumed. Providing water that is safe for drinking and other intended uses is crucial to prevent diseases in the community. Chemical contaminants typically don't occur at levels that cause acute health effects, but long term exposure can lead to health problems. Microbial contamination however can cause acute outbreaks of disease, even at very low levels of contamination. Infected persons and animals shed high numbers of pathogenic microorganisms in their faeces. These can be viruses, bacteria, protozoa or helminths. Helminths are mostly an issue in hot climates, but the other three pathogens are relevant for the Netherlands as they are generally found in domestic wastewater. Key characteristics of relevant waterborne pathogens in the Netherlands are summarized in Table 14.

TABLE 14 CHARACTERISTICS OF RELEVANT WATERBORNE PATHOGENS IN THE NETHERLANDS

Pathogen	Carrier	Characteristics	
Viruses *enterovirus*	Human	Very small (25 nm), persistent in environment and treatment, very infectious	
Bacteria *Campylobacter* *E. coli O157:H7*	*Human* *Animal*	Small (0.2x5 µm), not very persistent, also spread by birds and water fowl	
Protozoa *Cryptosporidium* *Giardia*	*Human* *Animal*	Larger (3-6 µm), extremely persistent in environment and chemical treatment	

Wastewater treatment has little effect on these pathogens, and therefore these pathogens are also found in surface waters affected by treated wastewater discharge. Livestock, wildlife and pets also contribute to contamination of surface water or other water sources. Ingestion of one or a few of these pathogens can already cause an infection, often leading to diarrhoea and sometimes to more serious diseases (WHO 2011). Therefore microbial risks are the primary concern for safe water supply. The WHO (world health organization) promotes a risk based approach for drinking water supply, because water quality analysis only provides limited verification of drinking water safety (WHO 2011).

Currently water at CTP De Ceuvel is supplied through the public centralised drinking water supply system of Waternet. The Cleantech Playground consortium studied possibilities to implement water collection and upgrading towards drinking water quality to achieve a locally closed water cycle. At De Ceuvel, canal water, rainwater and grey water are potential water sources for local drinking water supply. These sources are not protected against contamination with pathogenic microbes. In this chapter we assess whether these alternative systems could provide drinking water that complies with the Dutch drinking water standards with respect to microbial safety. Chemical contaminants may also be relevant for alternative water supply systems (Etchepare and Van der Hoek, 2015), however in the current study the focus is on microbial contaminants since they form an acute health risk.

4.2 Introduction to quantitative microbial risk assessment

Microbial contamination with pathogenic viruses, bacteria or protozoa is relevant even below detection limits. Furthermore their occurrence can be highly variable, especially in small scale systems. Drinking water is tested for the absence of *E. coli*, an indicator bacteria present in high numbers in faeces of warm blooded animals. Detection of *E. coli* is a clear indication of recent faecal contamination, however outbreaks of disease have occurred when *E. coli* was not detected. Therefore a routine water quality analysis doesn't guarantee continuous safety. Besides routine monitoring, water companies in the Netherlands have the legal requirement to perform quantitative microbial risk assessment (QMRA) every three years (Bichai and Smeets 2013). The QMRA approach explained here is applied by Waternet for the current water supply. A similar approach will be applied to various alternative water supplies for De Ceuvel. The QMRA approach is illustrated in Figure 12 and described in detail in VROM (2005).

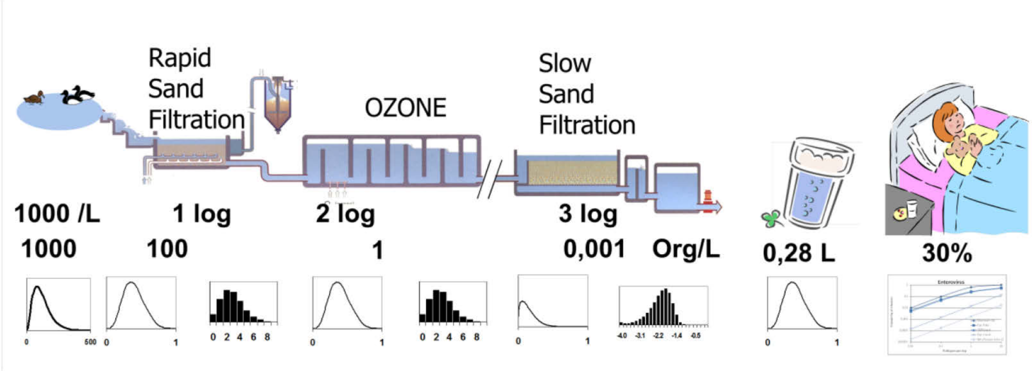


FIGURE 12 ILLUSTRATION OF THE QMRA APPROACH

QMRA starts by monitoring (or estimating) levels of pathogens in the source water taking into account the variability of contamination due to seasonality or events like CSO (combined sewer overflow) due to heavy rainfall. Then the removal of pathogens by drinking water treatment is estimated either by monitoring the removal of indicator organisms by the treatment system, or by using process models published in scientific literature. This removal is expressed on a ^{10}log scale, e.g. 2 ^{10}log equals 99% removal. Because viruses are very small they are poorly removed by filtration, and they can survive some levels of disinfection. Protozoa like *Cryptosporidium* are larger, but are not affected by chemical disinfection. Because the various pathogens pose different challenges to drinking water treatment, the risk is assessed for four index pathogens: enteroviruses, *Campylobacter* bacteria, *Cryptosporidium* and *Giardia*. For the study of the decentralised systems at De Ceuvel, literature reviews about treatment efficacy were used, since the systems were not built or in operation at the time of the study (LeChevallier and Au 2004, Smeets et al. 2006, Hijnen and Medema 2010, KWR Watershare 2015). These reviews made clear that pathogen removal at full scale is generally less effective than at laboratory scale. Upscaling of technology, varying operational conditions and wearing of materials over time lead to less removal in practice than the potential removal reported in scientific literature. For the alternative systems at De Ceuvel both the potential removal (e.g. a newly installed system) and the expected removal (long term performance in practice) were estimated in the risk assessments.

The concentration of pathogens in drinking water is estimated by applying the estimated removal to the pathogen concentration. The average daily consumption of unboiled drinking water in the Netherlands is 0.28 litres per person per day, varying between 0 and 2 litres (Mons et al. 2007). Using this variable consumption, the exposure (dose) to pathogens is calculated. A dose-response relationship is used to calculate the risk of developing an infection at this level of exposure. Thus the daily risk of infection is calculated and from that the annual risk of infection. To incorporate variability and uncertainty in the risk estimate, a stochastic approach is used. Each element in the risk assessment is described by a probability density function and these are combined in a Monte Carlo simulation to estimate the risk (Schijven et al. 2011). The theoretical risk of infection needs to comply with the legal requirement of one infection per 10.000 persons per year, which roughly equals a concentration of one pathogen in one million litres of water.

4.3 Centralised drinking water supply from surface water

The centralised water supply is fed by two water treatment systems, the Weesperkarspel system treating polder-water (described in Chapter 3) and the Leiduin system treating water from the river Rhine. Waternet monitors pathogen concentrations in the polder water, the river Rhine water and the abstracted dune water every three years with biweekly samples. Rhine river water is contaminated by sewage, and therefore the pathogens in Table 14 need to be removed 99.999% to 99.9999999% (5 to 9 ^{10}log removal). This is achieved by a series of water treatment processes including dune filtration, coagulation, sedimentation, rapid sand filtration, ozonation, activated carbon filtration and slow sand filtration. The polder water of the Weesperkaspel system is not directly contaminated by sewage, but zoonotic pathogens from the livestock and water fowl in the area are present in the source water.

The pathogen removal by both treatment systems was assessed by monitoring indicator organisms before and after each treatment barrier on a weekly basis. In addition tests were conducted where pathogens and indicators were spiked in the feed water of small scale pilot systems that represent the full scale systems. This information was combined with scientific literature to develop mathematical models that predict pathogen removal by treatment processes. By close monitoring and strict control of process conditions and strict operation and maintenance procedures the required pathogen removal is achieved continuously. Every three years a QMRA is preformed based on the collected information to verify that the produced water complies with the health based target.

The water is distributed through a closed, pressurized distribution system to prevent contamination of the drinking water. Maintenance and repairs are performed according to strict hygiene codes to prevent contamination while working on the system (Meerkerk and Kroesbergen, 2010). Random samples from home taps are taken as a final check of the supplied water in the household. Only about 0.01% of these samples were positive for *E. coli* indicating a possible contamination (Lieverloo et al. 2007).

4.4 Decentralised drinking water supply from surface water at De Ceuvel

Surface water at De Ceuvel is water from the river IJ. This river is fed from the Amsterdam-Rijn Kanaal (ARK), the Zaan and indirectly from the IJsselmeer (through the Randmeren) which is fed by the IJssel river, which comes from the river Rhine. The ARK, Rhine and IJsselmeer have been monitored by the drinking water companies for the presence of index pathogens over the last decades (Koenraad 1994, Hoogenboezem et al. 2000). Figure 13 shows the available data on the occurrence of pathogens in these waters combined as a complementary cumulative distribution (chance of exceedance, CCDF). The QMRAspot software (Schijven et al. 2011) was used to fit distribution functions to this data. Table 15 provides an overview of the fitted parameters and data characteristics.

TABLE 15 KEY PARAMETERS OF PATHOGEN CONCENTRATIONS IN RHINE BASIN AND FITTED PARAMETERS OF THE GAMMA DISTRIBUTION TO DESCRIBE VARIABILITY OF THESE CONCENTRATIONS.

Index pathogen	# samples	# positive	Mean (org/l)	Max (org/l)	*r*	*λ*
Enterovirus	106	82	0.75	13	0.34	1.9
Campylobacter	33	23	453	11,000	0.14	3200
Cryptosporidium	90	66	3.3	35	0.19	17
Giardia	90	66	3.5	148	0.17	20

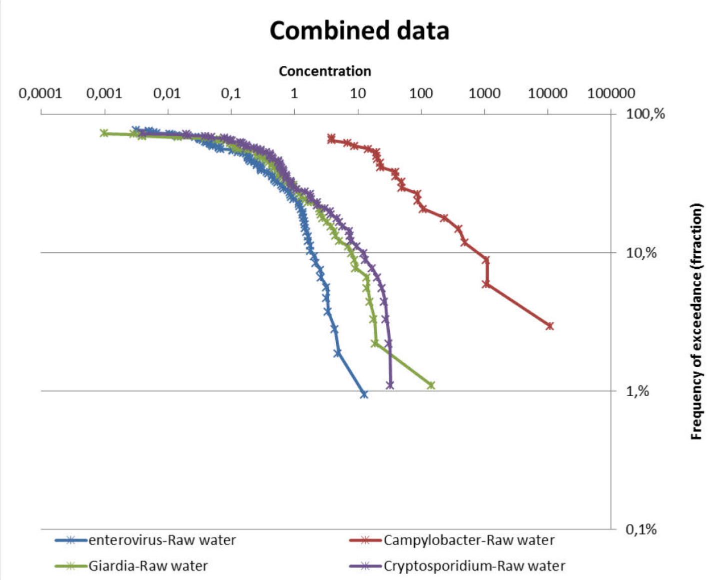


FIGURE 13 COMPLEMENTARY CUMULATIVE DISTRIBUTION OF PATHOGEN CONCENTRATIONS IN THE DUTCH RHINE BASIN

Removal by treatment

A treatment system to produce drinking water from surface water was proposed by AWWS. For QMRA only the treatment processes that are considered a microbial barrier were assessed. For the proposed treatment system these are:

- Pre-disinfection with NaOCl
- Multi-media filtration
- RO membrane filtration (total flow)
- UV disinfection (total flow)

Pre-disinfection NaOCl

Disinfection with NaOCl will not affect *Cryptosporidium*, and the effect on *Giardia* is very limited. Inactivation of enteroviruses and *Campylobacter* theoretically depends on the chlorine concentration, chlorine demand, exposure time (together expressed as CT in min*mg/l), temperature and pH (affects free chlorine level). In practice the inactivation largely depends on the design and operation of the system. Inadequate mixing, contact time distribution, and dosing control are known to occur in conventional system designs. The design and process conditions were not specified by AWWS, therefore assumptions need to be made. Table 16 provides an overview of expected inactivation of various pathogens under common disinfection conditions and illustrates the importance of a good hydraulic design. CSTR means continuously stirred tank reactor, which is a simple but effective way to model hydraulics in disinfection processes (Smeets et al. 2006b). A single tank with inflow and outflow where chlorine is dosed to the incoming water can be modelled as a single CSTR.

When the tank is baffled, each compartment can be modelled as a CSTR in series. Table 16 illustrates that improving hydraulics by baffling potentially has a significant effect on the level of inactivation that is achieved. The estimate of treatment efficacy can be made more accurate when design details, operating strategies and conditions (e.g. temperature variations) are known. For the current QMRA a design with 2 CSTR under the conditions in Table 16 is assumed (constant log removal as indicated). When the system is operational, microbial monitoring will be required to verify treatment efficacy.

TABLE 16 CALCULATED LOG INACTIVATION OF INDEXPATHOGENS UNDER ASSUMED PROCESS CONDITIONS AND VARIOUS HYDRAULIC DESIGN CONDITIONS

					Log inactivation			
CSTR	Free chlorine (Cl_2) (mg/l)	pH (-)	Temp. (°C)	Ct (min*mg/l)	*Crypto.*	*Giardia*	Virus	*E. coli*
1	1	8	10	10	0	0,16	1,7	1,8
2	1	8	10	10	0	0,17	2,8	3,1
3	1	8	10	10	0	0,18	3,6	4,1
5	1	8	10	10	0	0,18	5,0	5,8
10	1	8	10	10	0	0,18	7,5	8,8

Multi-media filtration

The type of media is not specified, nor the media characteristics or operational conditions. For the QMRA a rapid sand filtration is assumed. Such a filter can remove large pathogens like *Cryptosporidium* and *Giardia* to some extent but bacteria and viruses are hardly removed. Table 17 (from Smeets et al. 2006) provides an overview of published efficacy of rapid sand filtration. The MEC is the most likely achieved removal in practice for a well-designed, operated and maintained system. The range indicates the minimum and maximum reported removal and provides an indication of the uncertainty about the actual efficacy of a practical system. The MEC is used for the potential removal and the minimum for expected removal. However, the range of reported efficacies in Table 17 makes clear that media filtration may have no effect on any of the organisms. When the system is operational, microbial monitoring will be required to assess treatment efficacy.

TABLE 17 EFFICACY OF RAPID SAND FILTRATION AS REPORTED IN LITERATURE (SMEETS ET AL. 2006)

Organisms	Data characteristics			MEC		
	Studies	Data	FS-index[a]	MEC	50%ile	Range
Viruses	12	63	3.2	0.8	0.6	0.1 – 3.8
Bacteria[b]	12	109	3.2	0.6	0.6	0.1 – 1.5
Bacterial spores	11	102	4.2	1.3	1.4	0.0 – 2.9
Cryptosporidium	15	151	3.3	2.0	1.8	0.0 – 3.1
Giardia	10	124	3.3	1.7	1.6	0.0 – 6.5

[a] the higher the number (1-5), the more experiments resembled full scale and environmental organisms; [b] indicator bacteria (*E. coli*, coliforms, faecal streptococci)

RO Membrane filtration

Reverse osmosis (RO) membrane filtration in theory provides an absolute barrier against the indicator organisms since the membrane even removes salts. In practice this is not the case since leaking connections and seals can occur unnoticed and the membrane does not have an absolute maximum pore size. Membranes are designed to remove salt using the membrane material surface characteristics as well as the pore size (LeChevallier and Au 2004). A limited amount of leakage (e.g. 0.01%) hardly affects salt removal and will not be detected by increase of conductivity. However it does mean that microbial removal is limited to 4 logs. Table 18 provides an overview of reported virus removal by intact RO membranes as reported in literature.

Over time leakage is expected to occur due to aging of the material, especially due to chemical cleaning (CIP). Detection of leakage is challenging since the RO feed water contains few particles. Advanced detection limits have been developed for large scale systems that can detect when removal becomes less than 2 to 3 log units (Kruithof et al., 2001, Pype et al. 2016). For the QMRA 3 log removal of viruses, bacteria and protozoa is used as potential removal, and 2 log is used as the expected efficacy when sufficiently monitored in practice. When the system is operational, microbial monitoring and on-line integrity (conductivity) monitoring would be required to verify membrane integrity. However such an advanced monitoring system has not yet been developed for small scale. Alternatively a preventive replacement strategy could be considered, although there is no clear guideline for replacement based on microbial integrity.

TABLE 18 MEC VALUES FOR PATHOGEN REMOVAL BY INTACT MEMBRANES AND MONITORED REMOVAL IN PRACTICE DUE TO LEAKAGE AND MONITORING LIMITS (FROM SMEETS ET AL. 2006)

	pore size µm	Log removal Viruses	Log removal Bacteria	Log removal Protozoa	Operational level (log)[c]
Microfiltration	0.1-1	0 – 3.7	0-4.3	2.3 - >7	
Ultrafiltration	0.01-0.1	>6.5	>7	>7	4
Nanofiltration[a]	0.001-0.01			2.2	
Nanofiltration[b]	0.001-0.01			5.5	
Reverse Osmosis	0.0001-0.001	2.7-6.5			2-3

[a] Cellulose acetate membrane, [b] composite thin film membrane
[c] Operational removal level is limited by source water particle or sulphate concentration and the intensity of product water monitoring (total flow or per stack) based on practical examples.

UV Disinfection

For the QMRA the UV is assumed to be applied to the outgoing water (not recirculation). The inactivation of pathogens by UV is determined by the UV fluence or –dose (mJ/cm^2), which is a combination of the UV light intensity and exposure time (Hijnen et al. 2006). In practice this depends on the UV reactor design, flow rate, lamp type and age, water quality (UV transmission) and operational control. Hijnen et al. (2006) provides an overview of the current knowledge about UV disinfection. A reactor that has been certified with biodosimetry protocol is preferred for drinking water disinfection. The design fluence (or REF) was not specified by AWWS yet. For this QMRA a REF of 40 mJ/cm^2 is assumed as this is very common for drinking water applications. Table 19 provides an overview of predicted inactivation of the index pathogens. The inactivation was calculated from the inactivation rate constant and the REF. When the calculated inactivation exceeds the MICmax (the level at which 'tailing' has been observed indicating no increase of inactivation at higher fluence) the MICmax is used in the QMRA instead. Since enteroviruses are a group of 64 different viruses, the removal of the most resistant tested enterovirus is used in the QMRA. When the system is operational on-line monitoring of process conditions (flow, UV intensity, UV transmission) will be required to assess treatment efficacy. When executed properly and with adequate maintenance and replacement, the expected removal will equal the potential inactivation in Table 19. Microbial monitoring is not expected to provide meaningful results after RO treatment and will therefore not be performed.

TABLE 19 CALCULATED INACTIVATION OF INDEX PATHOGENS BY UV DISINFECTION, GREY FIELDS ARE NOT USED IN QMRA

Index pathogen	Tested pathogen	*k* (cm^2/mJ)	REF (mJ/cm^2)	Inactivation	MICmax
Enteroviruses				4,8	
	Poliovirus I	0,135	40	5	5,4
	Coxsackievirus B5	0,119	40	5	4,8
Campylobacter		0,88	40	35	5,3
Cryptosporidium parvum		0,225	40	9	3
Giardia muris		0,122	40	5	2,4

QMRA calculation

The QMRA calculations were performed with the QMRAspot software (RIVM 2010) that is also used for the legislative QMRA of water utilities. The raw water data were entered as 'raw data' and were therefore modelled as varying concentrations. The treatment steps were modelled as mean efficacy as explained above, with Beta distribution parameter a set to 100. This results in very little variation of treatment efficacy and can be regarded as a point estimate. QMRAspot then performs a full analysis and simulation of the health risk using standard consumption (mean 0.27 l/day) and dose response data for the Netherlands. Table 20 summarizes the results.

TABLE 20 RESULTS OF QMRA CALCULATIONS

			Potential			Expected	
Index pathogen	Raw Mean (org/l)	Raw 95% (org/l)	Total treatment (log)	DW mean	Risk (inf/p*y)	Total treatment (log)	Risk (inf/p*y)
Enterovirus	0.75	13	11	$2.6*10^{-12}$	$<1*10^{-9}$	9	$8*10^{-9}$
Campylobacter	453	11,000	12	$4.4*10^{-10}$	$2.6*10^{-8}$	10	$2.6*10^{-6}$
Cryptosporidium	3.3	35	7.5	$3.3*10^{-8}$	$7.1*10^{-7}$	5.5	$7.1*10^{-5}$
Giardia	3.5	148	7.3	$1.9*10^{-7}$	$4.0*10^{-7}$	5.5	$4.0*10^{-5}$

Conclusions

Under the assumptions, the proposed treatment system should be capable of producing water that complies with the maximum risk guideline value of 1 infection per 10,000 persons per year. The QMRA assumes constant performance of the treatment processes at the proposed level and sufficient operation and maintenance. This requires skilled operators. Harvey et al. (2015) showed that the level of training has the greatest impact on water quality compliance. For De Ceuvel this means that a local community member would be insufficiently skilled to take responsibility for water supply. Current (online) monitoring technologies are not capable yet to guarantee continuous safety in an independently operated decentralised system. Monitoring, operation and maintenance would need to be performed by a specialized company, e.g. Waternet. The additional costs and environmental impact of this need to be taken into account when evaluating this option. Monitoring of pathogens in raw water, indicator removal and operational conditions to perform QMRA according to the guidelines would also require substantial resources.

4.5 Drinking water from grey wastewater at De Ceuvel

Grey water could be considered as an alternative water source at De Ceuvel. The advantage of grey water is that the production and demand are balanced. When more water is used, also more grey water becomes available to produce water. Water losses occur at De Ceuvel due to consumption, irrigation, evaporation and spilling (e.g. during cleaning). For this study we assume that losses are supplemented with water of a quality that is at least equal to the grey water quality. Although grey water can contain many chemical pollutants (Etchepare and Van der Hoek 2015), in this QMRA we only look at the microbial water quality aspects. Harvested grey water will mainly be contaminated by activities around the sink such as washing hands after toilet visits, preparing food and cleaning of the offices. A limited literature study was conducted to estimate the level of contamination of grey water at De Ceuvel with pathogens. Pathogens have rarely been quantified in grey water reuse studies, and findings show a broad range of concentrations. Quantification of faecal indicator organisms in grey water systems has been performed to a larger extent. Results indicate a broad range of faecal contamination level across systems. The faecal indicators and pathogens are assumed to come (indirectly) from humans. This can be a more or less constant input of faecal matter e.g. after defecation or compost handling, or could be peak loads e.g. after vomiting in the sink, cleaning sanitation equipment or washing a baby. These peak incidents may be rare but seem realistic for De Ceuvel. The prevalence of illness in the community can vary significantly and since it is a small community with limited water use, single persons can have a large impact on the grey water quality.

Studies have addressed various sources of grey water, generally including showers and baths which are currently not installed at De Ceuvel. Birks et al (2004) analysed water from sinks at a stadium for *Cryptosporidium* and *Giardia*. Data from the sink seems more appropriate for De Ceuvel than data from the shower. Enterovirus was only tested by O'Toole et al. (2012) who found presence in 8% of grey water 100 ml samples. For the risk assessment we translated this into 0.8 PVE/l for the best estimate, and 10 PVE/l for the conservative estimate. *Campylobacter* were not detected by Birks et al. (2004), however based on the concentrations of enterococci and *Campylobacter* in wastewater and surface water, *Campylobacter* are expected a level 1,000 times lower than enterococci. This was used in the risk assessment.

Due to the large uncertainties about the site specific level of contamination at De Ceuvel, risk assessment was performed for a best estimate (approx. mean of reported data) and conservative estimate (approx. 95 percentile of reported data). Table 21 provides an overview of the parameters used. These point estimates were entered as very narrow distributions in the QMRAspot software (Schijven et al. 2011) resulting a point estimate of risk.

TABLE 21 PARAMETERS OF PATHOGEN CONCENTRATIONS IN GREY WATER FOR BEST ESTIMATE AND CONSERVATIVE RISK ASSESSMENT.

Index pathogen	Best (org/l)	Conservative (org/l)
Faecal enterococci *	800	1600
Enterovirus	0.8	10
Campylobacter	0.8	1.6
Cryptosporidium	0.4	1.2
Giardia	0.6	1.2

* Faecal enterococci is not pathogenic, it is included as a reference for the level of faecal contamination

Removal by treatment

For grey water treatment we assumed the efficacy of a home water treatment system consisting of RO membrane filtration and UV disinfection. The pathogen removal by large scale RO membranes was discussed in Paragraph 4.4. Small scale RO membranes are potentially less reliable since they are produced at very low costs and installed in relatively simple household water treatment systems. However, literature about the reliability of these systems is lacking. Producers of these systems advertise over 6 log removal by membrane filtration, although certification in the US is maximized at 3.3 log removal (NSF). Therefore we calculated the risk for both the 'advertised' removal (6 log) and the expected removal by large systems (3 log). UV disinfection depends on the UV radiation used. We assumed a minimum fluence of 20 mJ/cm^2 for home equipment to calculate the inactivation in Table 22. Hydraulics are expected to be less advanced in these simple systems, which means that the very high log reductions would not be achieved in practice. The UV disinfection can become less effective due to lamp aging and fouling without being noticed. Since such a system is installed in individual offices, the risk of insufficient replacement is higher. Therefore we assumed a 2 log reduction for all pathogens to estimate the expected risks in practice.

TABLE 22 CALCULATED INACTIVATION OF INDEX PATHOGENS BY UV DISINFECTION, GREY FIELDS ARE NOT USED IN QMRA

Index pathogen	Tested pathogen	*k* (cm^2/mJ)	REF (mJ/ cm^2)	Inactivation	MICmax
Enteroviruses				2.4	
	Poliovirus I	0,135	20	2.7	5,4
	Coxsackievirus B5	0,119	20	2.4	4,8
Campylobacter		0,88	20	17	5,3
Cryptosporidium parvum		0,225	20	4.5	3
Giardia muris		0,122	20	2.5	2,4

QMRA calculation

The QMRA calculations were performed with the QMRAspot software (RIVM 2010) that is also used for the legislative QMRA of water utilities. Data were entered as point estimates by choosing very narrow distributions for pathogen concentrations and removal. We combined the mean estimated pathogen concentrations with the advertised treatment efficacy to estimate the potential safety of such a system. We combined the high estimates of pathogen concentrations with the expected treatment effect in practice to estimate the expected risk in practice. Table 23 summarizes the results.

TABLE 23 RESULTS OF QMRA CALCULATIONS FOR GREY WATER REUSE

	Advertised			Expected		
Index pathogen	**Raw (org/l)**	**Total treatment (log)**	**Risk (inf/p*y)**	**Raw (org/l)**	**Total treatment (log)**	**Risk (inf/p*y)**
Enterovirus	0.8	8	$4.0*10^{-7}$	10	5	$5.0*10^{-3}$
Campylobacter	0.8	10	$4.4*10^{-5}$	1.6	5	$8.8*10^{-4}$
Cryptosporidium	0.4	9	$9.2*10^{-9}$	1.2	5	$2.7*10^{-4}$
Giardia	0.6	9	$1.3*10^{-9}$	1.2	5	$2.7*10^{-5}$

Conclusions

Treating grey water with an advanced household water treatment system could potentially provide safe drinking water. However the actual performance of the system on long term taking into account the reliability of mass-produced small scale household treatment systems, the risk is expected to exceed the Dutch standards for microbial drinking water safety. The most important uncertainty is the likelihood of a high level of contamination when an infected person contaminates the sink. This would very likely cause the infection to spread to people using that water to drink after treatment. Compared to the decentralised surface water system, the grey water reuse systems would be even more decentralised, with a treatment system in each office (house boat). Therefore the aspects of monitoring, operation and maintenance and performing QMRA would also become more important. The risk assessment doesn't take into account the issues of disposing RO concentrate with high salt content and the fact that the systems need to be replaced regularly.

4.6 Drinking water from harvested rainwater at De Ceuvel

Rainwater is also considered as an alternative water source at De Ceuvel. However, the quantity of rainwater and how it is distributed in time may mean that it cannot be regarded as the single source for De Ceuvel. Due to the low mineral content and the potential chemical contaminations (e.g. air pollution from industries and traffic) in rainwater, there may also be chemical and physical health issues with using rainwater as drinking water (Chapman et al., 2006). However in this QMRA we only look at the microbial water quality aspects. Harvested rainwater will mainly be contaminated by the rooftop surfaces that are used to collect it. The 'first flush' of rainwater generally contains a higher level of contamination and should be diverted away from the rainwater storage. The contamination present in harvested rainwater at De Ceuvel has not been assessed. Therefore data from literature was used to assess the potential health risk. Pathogens have rarely been quantified in rainwater harvesting studies, and findings show a broad range of concentrations. Quantification of faecal indicator organisms in harvested rainwater has been performed to a larger extent (Figure 14). Results indicate a broad range of faecal contamination level across systems. The ratio between faecal indicators and pathogens depends on the faecal source (human, type of animal), the prevalence of illness in communities and the presence of other sources of faecal indicators. Studies indicate that a large proportion of harvested rainwater is faecally contaminated, but the levels of pathogens are very uncertain.

The *E. coli* data from Holländer et al. (1996) could be considered as the best estimate for the variation of faecal contamination between sites and in time in Western Europe. This variation can be described by a Gamma distribution with r=0.03 and l=10000 (a highly variable concentration with mean 300 CFU/100 ml).

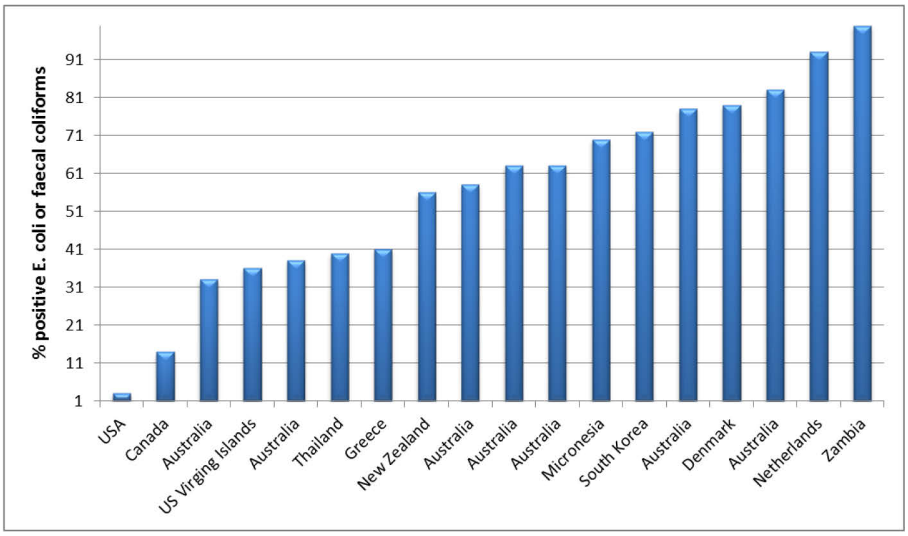


FIGURE 14 REPORTED DETECTION OF FAECAL INDICATOR BACTERIA IN HARVESTED RAINWATER IN VARIOUS COUNTRIES

Birds could be considered the most likely faecal sources for contamination of harvested rainwater. Using the minimum and maximum concentrations of *E. coli* and *Campylobacter* in gull faeces, their ratio would be in the range of 50 to 1000 (Soller et al. 2010). No *Giardia*, *Cryptosporidium* or enterovirus would be expected based on this data. However Oesterholt (2007), Ahmed et al. (2011) and Albrechtsen et al. (2002) did find both protozoa in harvested rainwater. None of the studies reported on viruses, since no human faecal input is expected for rainwater. Some studies have reported on transportation of human pathogens through air that then contaminate rainwater even before harvesting (Zhu 2004).

Due to the large uncertainties about the site specific level of contamination at De Ceuvel, risk assessment is performed for a best estimate (approximate mean of reported data) and conservative estimate (approximate 95 percentile of reported data). Table 24 provides an overview of the parameters used. These point estimates were entered as very narrow distributions in the QMRAspot software (Schijven et al. 2011) to make a point estimate of risk.

TABLE 24 PARAMETERS OF PATHOGEN CONCENTRATIONS IN HARVESTED RAINWATER FOR BEST ESTIMATE AND CONSERVATIVE RISK ASSESSMENT.

Index pathogen	Best (org/l)	Conservative (org/l)
E. coli*	300	1200
Enterovirus	0	0.01
Campylobacter	3	24
Cryptosporidium	0.06	0.19
Giardia	0.35	1.1

** E. coli is not a pathogen, it is included as a reference for the level of faecal contamination*

Removal by treatment

A Village Pump (http://www.villagepump.org/) is demonstrated at De Ceuvel as a treatment method that is using rainwater as source water. The system uses a hand pump to feed an ultrafiltration membrane unit. The intact ultrafiltration membrane is a very effective barrier against pathogenic organisms. However it is a single barrier and a failure or leakage can cause a significant decrease of efficacy without being noticed. The Village Pump documentation claims the following efficiencies for pathogen removal based on the membrane specifications.

TABLE 25 REPORTED REMOVAL EFFICACY OF UF MEMBRANE REPORTED FOR THE VILLAGE PUMP

Viruses	> 99.99% (log 4) [2]
Bacteria	> 99.9999% (log 6) [3]
Cyst removal	> 99.9999% (log 6)

The information in Table 25 and Table 18 is based on large scale treatment using advanced on-line integrity monitoring. The Village Pump doesn't have an integrity monitoring system, so it is unclear how and when integrity breach will be detected. Still for the current risk estimate the 4 log reduction was used to demonstrate the approach.

QMRA calculation

The QMRA calculations were performed with the QMRAspot software (RIVM 2010) that is also used for the legislative QMRA of water utilities. Table 26 summarizes the results.

TABLE 26 RESULTS OF QMRA CALCULATIONS

	Best estimate (mean)			Conservative estimate (95%)		
Index pathogen	Raw Mean (org/l)	Total treatment (log)	Risk (inf/p*y)	Raw 95% (org/l)	Total treatment (log)	Risk (inf/p*y)
Enterovirus	0	4	NA	0.01	4	$1.2*10^{-4}$
Campylobacter	3	6	$3.6*10^{-4}$	24	4	$2.7*10^{-1}$
Cryptosporidium	0.06	6	$3.0*10^{-6}$	0.19	4	$9.8*10^{-4}$
Giardia	0.35	6	$1.6*10^{-6}$	1.1	4	$5.5*10^{-4}$

Conclusions

Under the assumptions, the ultrafiltration of the village pump system may not produce water that complies with the maximum risk guideline value of 1 infection per 10,000 persons per year. The expected levels of *Campylobacter* from bird faeces drives the highest health risk. Because the validation of bacteria removal is limited to six log removal, the safety of the water cannot be guaranteed. In practice the integrity of the membrane cannot be verified at this high level, and it will even be challenging to validate 4 log reduction used in the conservative risk estimate. Under the conservative assumptions, the risk from *Campylobacter* is very high, on average a 27% annual risk of infection (or 27% of the population likely to get at least one infection per year). The optional chlorination system of the village pump could probably disinfect *Campylobacter* to acceptable levels. However in the conservative estimate also *Giardia* and *Cryptosporidium* risks exceed the guideline by 5 and 10 fold respectively. Chlorine has little effect on these organisms, and therefore would not provide sufficient safety. Given the current knowledge about harvested rainwater quality, the village pump system cannot reliably provide drinking water that complies with the Dutch health target. In addition the water from the pump needs to be carried by hand to the offices. From developing countries it is well known that recontamination can occur during this secondary transport and in-house storage. For De Ceuvel a system with closed vessels that would prevent recontamination would need to be developed. For the rainwater system the same aspects of monitoring, operation and maintenance are relevant as for the decentralised system.

4.7 Conclusions on safety of local drinking water supply options

In conclusion, it is possible to produce safe water in a decentralised system. This requires advanced treatment technologies and strict monitoring and maintenance. The latter will be challenging for consumers with limited knowledge of health risk and the technologies (Harvey et al. 2015). Replacement of membranes or UV-lamps which appear to be still functioning may be considered non-sustainable and costly by end users, thus compromising safety. To reach current drinking water safety standards with these point of entry or point of use systems, more sensitive and reliable sensors are needed and human perception and behaviour need to be taken into account. The cost and sustainability of these systems including the required monitoring and maintenance (by a qualified company) was beyond the scope of this study, but needs to be addresses in the total feasibility of decentralised solution.

5 Financial considerations, institutional aspects, user and stakeholder experiences

5.1 Introduction

In urban areas, utilities such as power, heat and drinking water supply, but also wastewater collection and treatment are usually centralised. Households and offices are connected to a large scale network, operated and managed by centralised utility companies (e.g. Waternet) that provide the different services households need. Centralised utilities for water, electricity and heat in the developed world have been in place for decades and their business model has not changed much since then. Robust, large-scale systems were built to supply as many people as possible, who pay for their resource consumption and through periodic fees. Products are generated in centralised plants – where safety and quality are closely monitored - and delivered to customers through an extensive distribution network. End users pay not only for the products itself, but also for the service of having it delivered, for operation and maintenance of the plants and network, for safety and quality insurance.

An alternative to the centralised utility system is the implementation of decentralised technologies - or micro-utilities - such as small scale solar and wind energy production, local wastewater treatment or small scale drinking water production. These emerging technologies are subject to optimisation, thus are not immune to failure with respect to financial, social, health and safety aspects. Implementing micro-utilities increases the share of operations users need to be responsible for, thus increasing the likelihood of failure of the systems, due to less expertise. Finally, although the numbers of people affected by the failure of one micro-utility is less than for one centralised utility, the likelihood of failure is higher with micro-utilities since the number of systems is higher. Decentralised systems do not necessarily suit the needs of any local community, as each of these technologies require specific environmental, spatial or social conditions.

In this chapter financial considerations of centralised and decentralised utilities are presented and discussed. Furthermore, the results of the research conducted on the legal and institutional aspects of De Ceuvel are reported, as well as specific user behaviour and experiences at De Ceuvel, including survey results.

5.2 Financial considerations

The De Ceuvel situation as it is today can be interpreted as a hybrid micro-utility system that uses both on-grid and off-grid utility systems and remains in-between a conventional area supplied with centralised utilities and an alternative area fully supplied with decentralised utilities.

5.2.1 Centralised, hybrid (real) and decentralised De Ceuvel cases

To study the financial aspects of utility systems for De Ceuvel, 3 cases have been shaped:

1. Virtual De Ceuvel case, fully connected to the common centralised utilities.
2. Real De Ceuvel case, partially providing utilities in a decentralised manner.
3. Virtual De Ceuvel case, fully providing its utilities in a decentralised manner.

The real case scenario translates into a hybrid system, where drinking water comes from a centralised connection, but toilets do not use water for flushing and grey water is being purified on site, so no wastewater is discharged to the centralised sewer (only wastewater from the De Ceuvel Café). The virtual case scenario in which the utilities are fully provided in a decentralised manner is a complete off-grid system that also uses a decentralised drinking water production system. The total operational costs for the water system are relatively comparable for cases 1 and 2. However, due to the high yearly costs of water quality monitoring, when following the guidelines (Ministry of Infrastructure and Environment: 'Inspectierichtlijn analyse microbiologische veiligheid drinkwater') the operational costs for the water system are much higher for case 3. Thus, in the current regulation context regarding water quality monitoring, it is not financially interesting to implement a decentralised drinking water production unit.

To ensure high quality and safety of the drinking water produced in a decentralised unit, the party responsible for the operation of the system must conduct an extensive quality monitoring program. This program costs around € 13,000 per year and is supervised by the ILT (Inspectie Leefomgeving en Transport) from the Ministry of Infrastructure and Environment.

Implementing clean technologies on a household and neighbourhood scale requires significant investment by the user. Comparing the analysis conducted on both energy utilities and water utilities, it appears that setting up energy integrated micro-utilities (heat pumps, heat exchangers and PV panels for instance) is financially more profitable for users than water micro-utilities. Decentralised wastewater treatment solutions might be financially interesting, but decentralised drinking water production systems are not, due to the mandatory program for water quality monitoring.

5.2.2 Office park (De Ceuvel) and residential cases

De Ceuvel is actually a very specific situation with 15 offices, resulting in a very low consumption of water, because of the installed composting toilets, but also because of the lack of showers. It is interesting to compare centralised and decentralised water systems in a residential neighbourhood as well. Therefore the overall costs (i.e. not the consumer price, but the actual costs of production and distribution) were compared at two different scales:

1. An office park of 15 offices, inspired from the De Ceuvel real case.
2. A residential neighbourhood with 15 families, comparable to the future Schoonschip case (but with a different scale and different systems from the real project).

TABLE 27 DESCRIPTION OF THE COMPARED SYSTEMS

	Centralised		**Decentralised**	
	De Ceuvel	Schoonschip	De Ceuvel	Schoonschip
Drinking water	Municipal supply		Reverse osmosis unit using water from the canal	
Grey water	Discharged to the sewer, purified in municipal wastewater treatment plant		On-site biofiltration, discharge into the ground	On-site biofiltration, discharge into the canal
Toilet waste	Flushed to the sewer, purified in municipal wastewater treatment plant		Collected with dry toilets and composted	

All costs for water production, distribution, consumption, collection, purification, quality monitoring, management, maintenance and operation are considered here. The technical solutions used in this model do not represent the real solutions that will be implemented on the Schoonschip site in 2016. The selected solutions for the model have been used for both Schoonschip and De Ceuvel site with 5 inhabitants/users per unit for coherence purpose, in order to compare different scales of application of the same systems, used on De Ceuvel (Table 27). The scale of the Schoonschip project has been scoped to 15 households, in order to compare it with the 15 offices of the De Ceuvel case (Table 28). The real Schoonschip project includes 47 households.

TABLE 28 SUMMARY OF THE COMPARED FLOWS

Flow (m^3/year)	**Centralised**		**Decentralised**	
(- = consumption)	De Ceuvel -	Schoonschip -	De Ceuvel -	Schoonschip -
(+ = production)	15 offices	15 households	15 offices	15 households
Drinking water (-)	837	3146	540	2700
Grey water (+)	540	2700	540	2700
Toilet wastewater (+)	297	446	0	0
Dry toilet waste (+)	0	0	0.8	1.1

It appears that a decentralised water system is much more expensive in comparison to a centralised water system, mainly due to costs of operation and maintenance and the mandatory program for water quality monitoring in drinking water production (Figure 15).

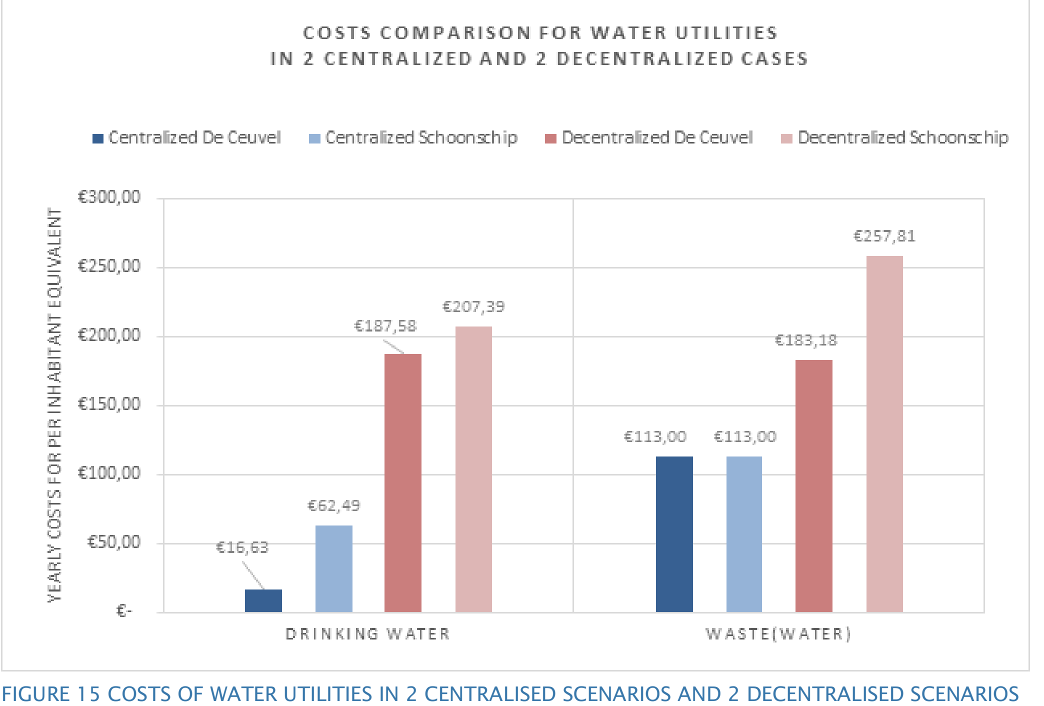


FIGURE 15 COSTS OF WATER UTILITIES IN 2 CENTRALISED SCENARIOS AND 2 DECENTRALISED SCENARIOS

Producing drinking water in a decentralised manner is approximately 3 to 10 fold more expensive than in a centralised manner. In that regard and from a risk management point of view, producing drinking water in a centralised system is better than in a decentralised manner. Nevertheless, because of future innovations that may reduce the costs of managing risks, monitoring water quality and controlling the efficiency of the purification systems, the costs of quality monitoring might decrease. The costs associated to centralised drinking water production and distribution are also location specific, so the situation in Amsterdam, with a relatively densely populated area, is not necessarily representative for other locations.

Based on the cost analysis, it appears that operation and maintenance carry a high share of the costs associated with sanitation solutions (when choosing for dry sanitation, i.e. composting toilets and individual grey water treatment). Results also show that in the real case of De Ceuvel, dry sanitation happens to be a few euros more expensive per person per year, compared to a centralised solution, even though the main operation and maintenance tasks are being performed by volunteers from the community, as part of their involvement in maintaining the site. When operation and maintenance labour costs are charged with a conventional rate, the decentralised sanitation solutions used on De Ceuvel become more expensive than the centralised solutions (€ 70 and € 144 per person per year difference for De Ceuvel and Schoonschip case respectively).

5.2.3 Overall financial analysis results

Concerning drinking water production, quality monitoring appear to be the main costs carrying aspect, making decentralised drinking water production 3 to 10 fold more expensive compared to centralised drinking water production. Only when the costs for quality monitoring are reduced with about 90%, decentralised drinking water production might be economically more favourable, but this depends highly on the applied system and e.g. intensity of use.

When labour costs for operation and maintenance are minimized by the deployment of volunteers in decentralised wastewater treatment, overall costs can be comparable with centralised treatment, but such a comparison is not completely fair. Furthermore, in the current costs for centralised drinking water production and wastewater treatment, several additional costs are included, like costs for environmental protection, research & development and additional municipal and governmental tax.

5.3 Institutional aspects

Legislation and responsibilities regarding decentralised water technology are not very clear. While seeking for information, the institutional environment around decentralised water initiatives became clearer to the research consortium.

5.3.1 Individual Wastewater Treatment (IWT) and institutions

Under the Environmental Protection Act in the Netherlands, Dutch municipalities have a duty to make effective arrangements for the collection and removal of all wastewater originating from properties within their jurisdiction. According to Rijkswaterstaat, since January 1st 2005 all untreated discharges must be remediated, including in areas where there is no sewerage present. In such areas, wastewater has to be treated in Individual Wastewater Treatment, or ‘IWT’ (*Individuele Behandeling van Afvalwater, ‘IBA’*, in Dutch) facilities before discharge into soil or surface-waters. IWT include different types of systems, the most common is the septic tank. Biorotors, oxidation beds or constructed wetlands are other examples of systems assimilated to IBA systems.

While Rijkswaterstaat is responsible for managing water quality throughout the Netherlands, the water boards are in charge of the purification of municipal wastewater, and the municipalities are responsible for collection of municipal wastewater, runoff and groundwater. Thus, water boards and municipalities also have to cope with IWT systems discharging purified wastewater into soil and groundwater.

According to the Environmental Protection Act (*Wet Milieubeheer*) Article 10.33, municipalities are responsible for the maintenance of municipal IWTs as part of their administrative duties. The standards that these facilities should meet are therefore stated in the municipal sewage plan (*Gemeentelijk RioleringsPlan, GRP*). The 2016- 2021 municipal sewage plan for Amsterdam (https://www.waternet.nl/media/88323/grp_amsterdam_2016-2021_-_definitieve_groene_boekje.pdf) does not specify regulations for IWTs outside of the environmental boundaries set in the Environmental Protection Law. However, it does specify the intention to increase the implementation of IWTs in innovative projects. Before 1st January 2008, newly implemented water discharging facilities were required to request a permit, for which the requirements are described by the CIW/CUWVO (Co-ordination Committee on water management and the implementation of the Pollution of Surface Water Act). In 1999, the CIW/CUWVO published the latest report available on this topic, '*Individuele Behandeling van Afvalwater IBA-Systemen*', relating to discharges of domestic wastewater from private homes. In this document the requirements for quality monitoring are described and the specifications for maintenance of IWT systems are detailed in Appendix II.

5.3.2 Needed permits

The De Ceuvel association, this is the governing body uniting the renters, needed to get the following permits before they were allowed to start building:

1. A change to the zoning plan (bestemmingsplan) for the whole ground;
2. A building permit for each individual boat;
3. A permit to discharge water (disposal of effluent).

Permits 1 and 2 were needed and obtained from the municipality (Stadsdeel Noord) and permit 3 was obtained from the Omgevingsdienst Noordzeekanaal (ODNZK), but actually instead an environmental permit (*omgevingsloket vergunning*) should have been obtained from the Ministry of Infrastructure and Environment.

1. In the Netherlands, establishment of any installation or business at a particular location must be in-line with the municipal zoning plan (bestemmingsplan). With zoning plans, the municipality establishes the final destination of land and buildings. The plan provides detailed rules on all kinds of issues, such as houses, streets, shops, factories, forests and the like. The zoning plan is the only plan with regard to spatial planning, which establishes rights and obligations. Industries impacting the environment or considered as potentially dangerous for local citizens will have to be located further than a certain distance from any living area, which also appeared as a main obstacle for De Ceuvel implementation, due to the environmental activities on-site (e.g. waste treatment). Because the De Ceuvel site was not zoned as a working area but only as a "road", building creative offices was not in line with the Buiksloterham zoning plan. Therefore, a submission for a zoning plan restructuration had to be submitted to the local municipality (Stadsdeel Noord). In July 2013, the procedure with Stadsdeel Noord, which lasted 9 months, ended with the approval of the zoning plan restructuration that allowed De Ceuvel to be a building area. For individuals or organizations that would like to build, demolish or modify a household, the zoning plan should not be an issue as long as the location of the household fits into a "living area", as defined in the local zoning plan.

2. Before starting any construction, whether it is a boat on the ground, a house, a living or working building, a building permit is required. The application for this building permit has to be submitted to the municipality (Stadsdeel), and will be studied regarding the relevant Housing Act and the relevant Building Decree (Bouwbesluit). This building decree can be found on the VROM website. In the implementation and use of decentralized clean technologies on a small scale, the first step in applying a building permit is important. Because the Building Decree sets out technical requirements for existing and new construction, including rules on every system providing basic utilities (such as drinking water supply, wastewater treatment, sanitation, heating, ventilation,

windows and others), the application for a building permit includes technical descriptions of all these systems. For each of these basic utilities, different existing solutions can be chosen (e.g. connection to the sewer for wastewater discharge) or the project owner can propose its own unusual solution (e.g. no connection to the sewer and on-site wastewater treatment). Hence, because municipality employees and departments are not necessarily familiar with these new solutions, implementing decentralised systems or clean technologies requires a significant amount of information and description to prove that the suggested solutions or systems are as efficient and safe as the common and well-known solutions. On the De Ceuvel site, application for building permits was of course required for each retrofitted boat the community wanted to install. The main difficulty was to change the application for each boat. Because each boat installed on De Ceuvel was different, a custom process was required for the design of the whole infrastructure installation (water, heat, aeration, insulation). Therefore, building a robust application was the first significant step Metabolic and the De Ceuvel community had to go through in order to be able to implement decentralised solutions for wastewater treatment, electricity and heating supply. The required level of specialized knowledge was quite advanced because of the highly technical content. Thus, specialized professionals (architects, civil engineers) must handle this part of the application for building permits pertaining to decentralised technologies. In the end, the De Ceuvel community received building permits on October 22nd 2013 for all the boats after a 6 month procedure. After receiving the building permits, people can note objections against the project within 6 weeks. No objections were received by the De Ceuvel building permit changes.

3. According to the Dutch discharge decree (water handbook of Rijkswaterstaat, Ministry of Infrastructure and Environment) a permit is required to discharge water. This permit is different depending on whether a business (*inrichtingen*), a household (*huishoudens*) or another actor (*buiten inrichtingen en huishoudens*) is enquiring it.
   Metabolic asked for a license through the Omgevingsdienst Noordzeekanaal (ODNZK) concerning purification and discharge of wastewater into the ground on De Ceuvel site. The activity decree (*activiteitenbesluit*) that Metabolic filled was, in fact, for businesses, although the De Ceuvel site fits into the “others” category (*buiten inrichtingen en huishoudens*), instead of business category. Thus, the De Ceuvel community should have enquired another specific license/permit for this activity: an environmental permit (*omgevingsloket vergunning*), delivered by the Ministry of Infrastructure and Environment and specific to this category of undefined actors (not households, not businesses).
   The activity decree (*activiteitenbesluit*) declaration was given quite easily by ODNZK, but just after the start of the project, ODNZK started to ask questions. Metabolic and Waternet could convince ODNZK that the infiltration of the effluents was done in a safe and monitored way and that the infiltration was part of an innovative project. ODNZK was flexible with the project; they accepted an easier way of monitoring the effluent quality than what is normally required[3]. The monitoring activities according to the normally required NEN norm (CIW 1999) are too costly to perform at De Ceuvel.

5.3.3 Quality monitoring of IWT

One main point arising after analysing the current legislation is that decentralised wastewater solutions are still unclearly covered by regulation. It is difficult to identify who, in the current legislative and institutional system, is responsible for monitoring and controlling

[3] http://www.infomil.nl/onderwerpen/klimaat-lucht/handboek-water/activiteiten/lozen-per-activiteit/technische/iba/#ActiviteitenbesluitenhetBesluitlozingafvalwaterhuishoudens

decentralised sanitation initiatives, since the number of such projects remains relatively low (STOWA & Rioned 2015).

Concerning De Ceuvel project, for instance, it is still unclear who is responsible for the quality monitoring of the decentralised systems. Throughout 2014, tests have been performed within the research program to monitor the quality of wastewater effluent discharged into the ground, but how will the monitoring of wastewater quality be conducted on a longer term, when the research program ends or focuses on other research areas?

While the current legislation requires every IWT system (15 small scale biofilters in the case of De Ceuvel) to be monitored twice a year on effluent quality, there is still no clear process and agreement for the stakeholders of De Ceuvel project regarding who and how should the quality monitoring of these systems be performed.

Based on our understanding of the mentioned legislation articles, the stakeholders who should be involved in that matter are the following:

- the waterboard Amstel, Gooi en Vecht, as the party supervising wastewater management in the area of Amsterdam;
- the municipality of Amsterdam, as the party responsible for individual wastewater treatment systems, as part of the municipal sewage plan;
- the water utility company Waternet, as the party commissioned by the waterboard and the municipality of Amsterdam to implement the municipal sewage plan;
- the De Ceuvel community, as initiator of the De Ceuvel project;
- Metabolic, as part of the project team, advisor and constructor of the sanitation systems on De Ceuvel site.

5.3.4 Local drinking water production and delivery

According to article 4 in the Drinking water law (Drinkwaterwet), only the drinking water companies are allowed to deliver drinking water. Therefore, decentralised drinking water production and delivery by other organisations is not allowed, due to the monopoly position of drinking water companies in the Netherlands. The only exceptions to this law are when the centralised delivery of drinking water is not efficient and there are no issues for public health.

By law, the priorities of the drinking water systems are:

1. the drinking water needs a guaranty that it is safe;
2. it needs to be produced in a sustainable manner and;
3. it needs to be produced against acceptable costs.

In theory, decentralised production of drinking water is allowed when these three priorities are fulfilled. However, to ensure that the drinking water quality is guaranteed, a comprehensive monitoring program is obliged, which will increase the costs, so it becomes difficult to still produce at acceptable costs. However, local drinking water production from ground water with a limited monitoring program is tolerated at camping sites in The Netherlands.

5.3.5 Struvite

Since 2015 the fertiliser law was adapted to include recovered phosphorus as legal fertiliser. In the Stowa 2015-34 report the following is written about struvite legislation:

"Struvite can be used as a phosphorus-containing fertiliser. At the beginning of 2015 legislation (Fertilisers Act (Implementation) Decree and Fertilisers Act (Implementation Regulations)) was amended and expanded to include the category 'recycled phosphates'. To be used as a fertiliser the recycled phosphates, including struvite, must meet the agricultural and environmental quality criteria according to the fertiliser legislation. In addition, struvite from sewage sludge must be treated in order to kill the majority of pathogens that may be present. This mandatory treatment stage has been included as a precautionary measure and may potentially be repealed in the future."

The scheme shown in Figure 16 describes how the legislation works. Struvite from wastewater is not from animal manure, and since it contains some organic matter, it does also not comply with the EG 2003/2003 norm. It does comply with the definition of recovered phoshphates according to the Dutch Fertilisers Act and therefore it is called '*herwonnen fosfaat*' (recovered phosphate), which can be legally applied.

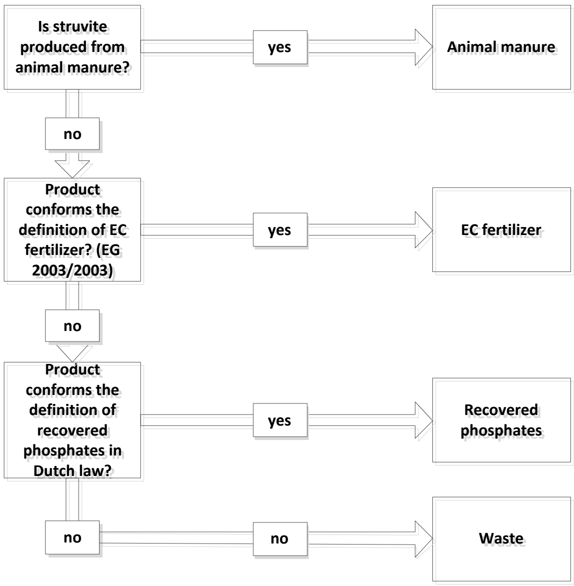


FIGURE 16 SCHEME OF THE FOLLOWING REQUIREMENTS FROM THE DUTCH FERTILISERS ACT FROM WHICH THE STATUS OF STRUVITE CAN BE OBTAINED (STOWA 2015-34)

Normally, only the definition 'recovered phosphate' within the Dutch Fertilisers Act is not enough for industrial customers to buy the struvite. They also need a REACH (Regulation for Registration, Evaluation, Authorisation and Restriction of Chemicals) declaration. All chemical compounds that are produced or imported in Europe, need to be registered under REACH. However, if the production volume is lower than 1,000 kg/year, this is not needed. The volume at De Ceuvel (and later scaled up projects) will be lower than 1,000 kg, so REACH is not applicable (Stowa 2015-34). Consequence of this is however that the produced struvite can only be sold locally.

5.3.6 Human compost

Bennink et al. (2015) state that there is no Dutch regulation on the composting of human excreta (Appendix I). However, comparable regulation can be found on treatment of sewage sludge and animal manure. Sewage sludge is not allowed to use as a fertiliser. Animal manure is allowed, but the regulation is focused on heavy metals and not on pathogens, as should be the case for human waste. To get application of human compost allowed in the Netherlands, two options are possible: 1) the compost needs to get an 'End-of-Waste' status or 2) the compost needs to comply with the '*Keurcompost*' norms.

End-of-Waste
The European Waste Framework Directive (EWFD) provides a so-called End-of-Waste (EoW) route. With an EoW status, potentially reusable waste streams like human faeces are no longer classified as "waste" but as "products" and will be exempted from the European waste regulations. Criteria for a waste stream to qualify for the EoW status are (Bennink et al. 2015):

- The waste stream is commonly used for specific purposes.
- There is a market or demand.
- The waste stream meets the technical requirements for the specific purposes and the legislation and standards applicable to products.
- The use of the waste stream has on the whole no adverse environmental or health effects.

The human compost at De Ceuvel is probably not safe enough to comply with the 'no health effects' criteria. For this, a longer storage time is needed or a higher temperature during composting. Because of the small scale and the possibility to use the compost locally, the first two criteria are easier to comply with. Since the compost contains organic matter as well as nutrients, it probably meets the technical requirements.

Keurcompost
Keurcompost is a certified high quality soil conditioner that is rich in stable organic matter. Due to the strict production requirements for *Keurcompost*, the product is guaranteed to be free of weed seeds, pathogens and non-soil components, unlike when raw organic streams would be used as soil conditioner (Bennink et al. 2015).

The human compost at De Ceuvel did not comply with the strict *Keurcompost* norms. The amount of detected indicator organisms for pathogens was too high, even after 11 months of storage. Also the ratios of Copper and Zinc compared to the nutrients content were too high in some samples. Other heavy metals were present in low enough concentrations.

It can be concluded that although there is no regulation in The Netherlands for human compost, the chance that it is legally allowed to apply it for commercial purposes is small. It is difficult to make the compost comply with the End-of-Waste or *Keurcompost* criteria.

5.3.7 Scalability and responsibilities
Research questions on the institutional aspect regarding scalability and responsibility were:

1. How can technologies on De Ceuvel be scaled to other projects?
2. What are the responsibilities of different stakeholders?
3. How can these responsibilities be developed towards the future?

Scalability
The De Ceuvel is a unique site, but the used technologies cannot be scaled up easily. The user acceptance of the composting toilets was quite low (see Chapter 6.3), and therefore these toilets probably will not be used at other sites. This means that the reduction in flushing water will be lower at other sites and a sewer system will be necessary. The production of grey water by households will be much higher, because they use showers and washing machines. The grey water will also be more polluted with for example soaps. The question is whether an individual grey water biofilter is still feasible then. The filters will

require more space than the ones used at De Ceuvel, because of the higher amount of water to be treated. On the other side, the monitoring at De Ceuvel proved that low-tech biofilters are able to treat grey water. On other sites, shared biofilters might be suitable for grey water treatment, however research is needed to prove that they are able to remove compounds like soaps and personal care products. AWWS developed a small scale mobile wastewater treatment system that can be used instead of biofilters (Appendix III). With this system, also the toilet wastewater can be treated.

Local production of drinking water is not advised when scaling up. The research at De Ceuvel showed that costs and the environmental impact of locally produced drinking water are not lower than centrally produced water, and that safety cannot be guaranteed. Next to that, the law in the Netherlands does not allow locally produced drinking water distributed by another party than the conventional drinking water companies. Considering these results, Waternet (as conventional drinking water company) will not continue with (research on) local drinking water production.

Responsibilities
At De Ceuvel, Metabolic, under command of the de Ceuvel association, has installed the grey water biofilters and the composting system. The association has become operator/manager of the systems after realisation, even though it is difficult to identify who, in the current legislative and institutional system, is responsible for monitoring and controlling decentralised sanitation initiatives (see paragraph 5.3.3). At other sites, it is still an option that a third party (e.g. a contractor) is doing this, but a more common option is that the municipality is responsible for this, forced by the Environmental Protection Act (Wet Milieubeheer). In Amsterdam, the water tasks of the municipality are executed by Waternet.

A trend is that citizens want to have more control of normally public utilities. However, Waternet (on behalf of the municipality and water board) has the responsibility for ensuring public health and therefore is collecting and treating wastewater. Technically, it is possible that citizens are treating their own wastewater (like De Ceuvel). In that case, a future task of Waternet can be to control whether this treatment is done in such a way that the risks for public health are minimalized. At De Ceuvel, this task is not executed by Waternet, but by the municipality (via the Omgevingsdienst Noordzeekanaal (ODNZK)), since the effluent of the biofilters was infiltrated in the soil and the compost is not yet exposed of externally. For future projects with individual wastewater treatment, it is therefore important to find out who controls public health risks. That party should also receive a sort of tax income to fulfil the control. This means that even when citizens are completely treating their own wastewater, they still need to pay some tax.

Waternet does not have a vision yet on future tasks and responsibilities regarding this issue. The experience on De Ceuvel helped to make a start getting such a vision, but more research and experience with bigger, more representative projects, is needed to finalise it. An important question is whether the responsibilities of Waternet can still be fulfilled, when tasks are being executed by citizens or third parties.

5.4 User behaviour and satisfaction
One primary aim of the Cleantech Playground was to build a community project with the involvement of participants who did not necessarily have specialized technical knowledge. The objective was to showcase how people can reinvent their relationship with resources (energy, water, food) around their domestic environments. From the beginning of this project, future users were invited to participate in construction activities at this Do-It-Yourself (DIY) eco-office park. Here information about user behaviour and survey results

about satisfaction of office renters on De Ceuvel is presented. Surveys were conducted during summer 2014 and December 2014. Results from the survey are shown as indicators of the general opinion of renters. While during Summer 2014, 8 companies (and users associated) completed the survey, this second survey was completed by 10 companies. The difference in the number of answers is due to additional companies who settled on De Ceuvel after the summer.

The survey of De Ceuvel renters showed that although high sustainability ambitions influenced their interest to be involved in the project, money was also one of the main motivating factors, as finding an office space in Amsterdam could sometimes be difficult and expensive. Renter motivations were very diverse and had and still have repercussions on their involvement in thinking, designing, prototyping De Ceuvel and technologies.

Users have been involved in different phases, but have significantly contributed to the preparation of the boats and construction of different clean technologies (particularly the water systems). The first milestone of their involvement is the signing of a sustainability manifesto in August 2013, in which they committed to changing their daily habits in order to fulfil the sustainability goals of the site. This includes reducing energy use in smart ways, using compost toilets instead of flush toilets, and being careful not to disrupt the functioning of the biological wastewater treatment system (i.e. biofiltration). In January 2014, this commitment was strengthened with the signing of an additional and updated sustainability agreement that came attached with an overview of the technologies installed on site. One of the important points of this agreement was to provide the user awareness about the proper functioning of the systems.

Updated Sustainability agreement for the Cleantech Playground at de Ceuvel - January 24th 2014:

> "Vereniging De Ceuvel is committed to high levels of sustainability."
>
> "In becoming a member of the de Ceuvel community, all of us become co-owners of the Cleantech Playground experiment and have a shared responsibility to help realize the project's ambitions. We agree to do our best to help achieve the collective targets for energy savings, responsible water management, nutrient cycling."
>
> "Collaboration is expected in user adjustments and research efforts."
>
> "To make the Cleantech Playground a success, we expect and require everyone's collaboration in following the user guidelines for the site."
>
> "DIY constructions and technologies are not perfect, and installation of the technologies is done at own risk."
>
> "Just as any other system, DIY technologies will need repair over time and may fail. It is a collective responsibility to maintain and replace the basic systems on site."

The average participation in the collaborative technical development was around 6 working days. Volunteers also participated sometimes in community building days or technical workshops, depending on their own interest. When asked for their opinion about the community aspects of the De Ceuvel project, renters brought interesting points, especially about the construction phase. First of all, participants were pleased to learn new skills (building, experimenting), meet a broader community of creative entrepreneurs and proud to show that a lot is possible with little money and strong will. Also, it appears that being their own decision makers was one of the most attractive and interesting point for the renters, as they were involved since the beginning of this project. It was also mentioned that involvement could have been stronger if communication was better by clearly defining the goals and targets of each action and decision. Negative points were also brought up, mainly focused on fairness. Because each renter and community member was not involved to the same extent, some renters were uncomfortable with a situation felt as imposed on them. Finally, it appears that organisation and planning could have been better managed within De Ceuvel community and with the active partners.

From the user feedback, we can draw preliminary conclusions regarding acceptance of the systems within a social environment. It is important to notice differences in users' evaluation for each technology (Figure 17). Grey water systems seem to be rated best, with no major drawback identified by the users.

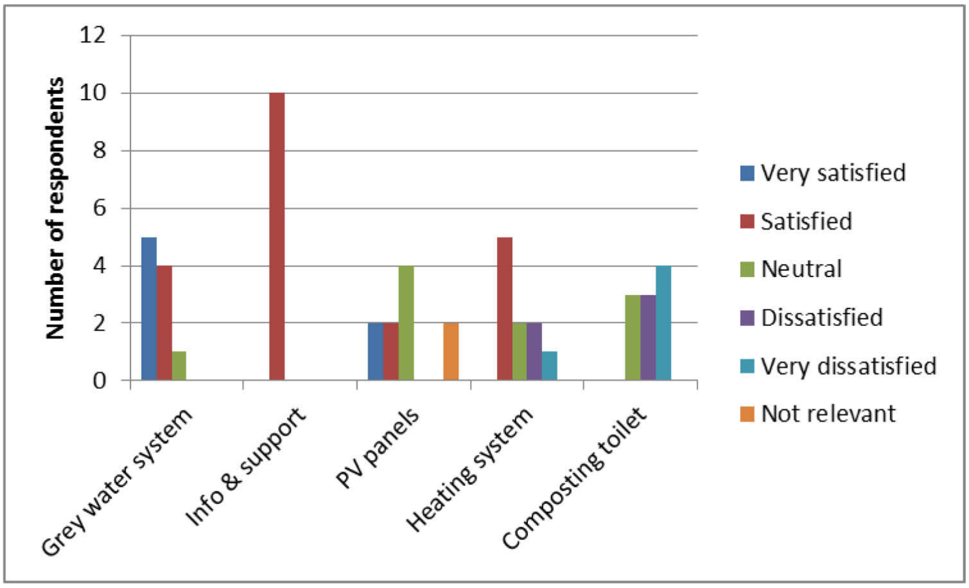


FIGURE 17 DE CEUVEL USERS FEEDBACK - OVERALL SATISFACTION RATE PER TECHNOLOGY

Feedback from users on De Ceuvel allows for a better understanding of which aspects of the clean technologies are problematic or satisfying. These results in Figure 17 show that users are generally dissatisfied with the composting toilets and post-composting process and operation, while users have a neutral or balanced opinion concerning the grey water systems and heating systems. In Table 29 are some of the most representative points that have been brought by the users, concerning both satisfying and non-satisfying aspects for each clean technology.

TABLE 29 DE CEUVEL USERS FEEDBACK - SATISFYING ASPECTS AND POINTS OF IMPROVEMENT PER TECHNOLOGY

	Satisfying aspects	Suggestions for improvements
Grey water systems	• Reuse water to grow plants • Easy to use • No connection to the sewer	• Integrate the system with a garden design
Heating systems	• Nice and warm feeling	• Rather use heating floors or walls instead of an air blowing system (dust and cold feeling) • Include programming and heating schedules
Composting toilets		• Cleaning assistance • Switch to fully automated units that deliver compost • Have 1 tumbler per toilet • Improve aesthetics • Increase capacity
PV panels	• Energy self-sufficiency • No maintenance	• Provide feedback and insights on energy production

5.4.1 Grey water systems

One important point to note concerns the grey water systems. In the summer 2014 survey, 30% of the respondents stated that they would not recommend the installation of this system to a friend and frequently reported smells and nuisances, showing a clear dissatisfaction with the technology. However, in the December 2014 survey 100% of the respondents stated that they were neutral or satisfied with the technology and communicated that smells and nuisances had been eliminated. This achievement in satisfaction follows the technical optimization performed during Fall 2014 (in between the two surveys): removing the settling drums of the systems. Beside the achievement of full users satisfaction, this operation did not lead to any efficiency drop in terms of water purification.

5.4.2 Heating systems

Results show that some of the users were dissatisfied by the heating systems. Indeed, one specific system broke due to a defect part that was replaced after the survey. Another main dissatisfaction point for the heating systems concerns the slow start of the heating system and lack of power. These issues can be explained by the following reasons:

- Heat pump based heating systems requires time to warm up, which issue can be fixed by not switching off fully the heating at night.
- Insulation in the boats is poor, leading to significant heat loss.

The main solution to ensure a sufficient heating is to fix insulation in the offices, which should have been the first priority when retrofitting the boats.

5.4.3 Toilets and composting

The majority of comments and recommendations concerns composting toilets and the post-composting tumbler. After using their toilet for several weeks, users transport pre-compost (partially composted faeces + woodchip) to a bigger tumbling composter (Joraform) in a central location on De Ceuvel. The users rate their experience with this process as follows:

- Satisfied 10%
- Neutral 30%
- Dissatisfied 30%
- Never did it 30%

The most commonly reported concerns and solutions regarding the toilets process in general are reported in Table 30.

5.4.4 Why choosing clean technologies, if not for sustainability reasons?

It is interesting to understand which aspects of the daily-used appliances are the most important for users, beside sustainability. Indeed, sustainable technologies and systems will spread and be massively adopted by users, only if they meet basic needs and expectations that conventional technologies fulfil.

Considering different criteria susceptible to push customers to purchase and install specific technologies, respondents chose easy operation (22%) and efficiency (17%) as the two most important criteria. Financial savings (14%), price (11%) and operation costs (8%) are important economic drivers, followed by easy installation (11%) and aesthetics (11%). In the case of De Ceuvel, it appears that composting toilets are not easy to operate, leading to a difficult acceptation by the users. Of course these alternative systems require an adaptation period, so acceptation might increase over time.

TABLE 30 DE CEUVEL USERS FEEDBACK - ACTION POINTS REGARDING TOILETS AND COMPOSTING PROCESS

Concerns	Representatives feedback	Solution
Technology related	Capacity of the toilets is too low for the number of users	No optimization possible/change the type of toilet
	Rotation direction is unclear	Better written and oral communication
	Handle piece is too weak	No optimization possible/change the type of toilet
	Toilet is difficult to clean	No optimization possible/change the type of toilet
De Ceuvel related	Cleaning materials are lacking	Provide cleaning products
	Bringing the compost to the tumbling composter is uncomfortable	Improve safety by providing single-use gloves and masks
		Move tumbler to a dedicated location (community platform)
		Train one dedicated maintenance person
	One tumbler for the whole De Ceuvel is not ideal	Provide more tumbling composters (to discuss: more units will lead to more maintenance on different locations)
	Winter weather conditions might reduce the efficiency of the treatment	Build rain and wind protection for the tumbling composter (outdoor)
		Improve insulation of the boats (will improve the composting process within the toilet)

5.4.5 Overall user satisfaction

It is clear that the occurrence of uncontrolled phenomena such as smells and flies are not acceptable for users. It breaches the comfort level of conventional solutions they are used to. When solutions for each of these issues are implemented, the users are as happy with the clean technologies as they are with conventional systems. The first outcome of their feedback is that grey water systems are well accepted among the community, since the removal of the settling drums in Fall 2014. Most importantly, composting toilets are still not well accepted by most of the users: emptying the composting toilets is uncomfortable for users because it requires handling of human waste, as for cleaning the toilet; the toilet itself presents design weaknesses (mechanical parts breaking) and communication of operation guidelines can be optimized.

5.4.6 Symposium decentralised water and energy solutions

Because of the finalisation of this TKI research project, on the 15th of October 2015, a symposium took place at the office of Waternet. A general question during the symposium was: *Decentralised as fashion statement or necessary step towards a sustainable city*? A clear answer is not easy to give, because, for example, what is a sustainable water solution? This is among other depending on the particular case, but also the parameters, and delimitation. About 80 interested people attended the symposium (Figure 18), that included a site visit to De Ceuvel. In the afternoon an expert discussion was performed with a selected group of approximately 20 Dutch stakeholders.

FIGURE 18 PARTICIPANTS OF THE SYMPOSIUM DECENTRALISED WATER AND ENERGY SOLUTIONS

A number of important points in various presentations and during the subsequent expert discussion have emerged:

- (Decentralised) drinking water production is subject to strict legislation that guarantees that delivered drinking water is reliable, safe, acceptable and sustainably produced at acceptable cost. There is very limited room for experimentation. Safety and health are paramount.
- A major challenge is to combine the existing infrastructure with new innovative systems. Here it is a question: how to deal with bottom-up initiatives? Ultimately, there often seems to be a balance between flexibility and economy-of-scale.
- There have been many decentralised wastewater treatment initiatives. Not all the ambitious plans are realised, but purification of (grey) wastewater, for example in a constructed wetland, is possible and is frequently applied.
- There is a need for a dot on the horizon (vision) and applied (pilot) research into real (show) cases.
- While there is a strong relationship between water and energy, water isn't electricity. However, there may be much to be learned from the decentralisation of energy supply.

'Smart' carefree systems are important for public acceptance and smooth larger-scale deployment.

A multidisciplinary approach to the opportunities that arise remains necessary for further development of sustainable and cost-effective water and energy solutions.

A summary of the symposium and an overview of the given presentations are available online: http://www.kwrwater.nl/TKI_minisymposium_decentrale_water_en_energie-oplossingen/

6 Resume, recommendations and conclusions

6.1 Introduction

This project was implemented within the Top Sector Water. Within the various Top Sectors the government, entrepreneurs and scientists work together in so-called Topconsortia for Knowledge and Innovation (TKI). This TKI project 'Loop-closure Cleantech Playground Amsterdam' is part of TKI Watertechnology and focuses on the water cycle of De Ceuvel in Amsterdam North.

De Ceuvel is a workplace for creative and social enterprises in Amsterdam, the Netherlands. The former industrial plot has been turned into a sustainable urban development. The heavily polluted site features retrofitted houseboats as offices, placed on land, surrounded by soil-cleaning plants. Because of the temporary character of the site (it is rented for 10 years) and the polluted soil, the houseboats are not connected to the sewer system. Instead they are provided with dry composting toilets and individual biofilters for grey water treatment. The boats use conventional delivered drinking water, but desk research was done to study the feasibility of local drinking water production from a sustainability (by Life Cycle Assessment (LCA)), risk (by Quantitative Microbial Risk Assessment (QMRA)), legal and economical point of view. Although many sustainability issues are addressed at De Ceuvel (e.g. energy and local food production), this study focuses on water aspects.

The primary goal of this project concerning a small-scale pilot in Amsterdam North is to achieve closure of the cycle ‘as much as possible’ by applying innovative concepts and technological solutions. The performances of in particular the water-related technology have been monitored and evaluated in this TKI project in order to show clearly the applicability in a sustainable circular economy.

6.2 Resume

6.2.1 Grey water

A minimum amount of grey water is produced at the houseboats, because of the application of composting toilets and since the boats are used as office, they do not have showers or washing machines. Only five litres per capita per day is needed for drinking, food preparation and personal hygiene, compared to the current average of 25 litres in conventional offices and 128 litres in households in The Netherlands (Pieterse-Quirijns *et al.* 2009). The grey water is treated in individual low-tech biofilters, consisting of two pallet tanks filled with a mixture of gravel and sand, topped up with reed. The effluent of the filters is monitored before it is infiltrated in the soil and complies with the norms of individual wastewater treatment systems in The Netherlands.

6.2.2 Faecal matter

Composting toilets are being used in the boats on De Ceuvel, resulting in the production of less wastewater, but the human faeces have to be processed further. The users at De Ceuvel have to bring the faecal matter from their composting toilet periodically to a central composter (type Joraform). Possibilities for reuse of (parts of) the compost have been investigated in the TKI project. There is, certainly in the Netherlands, lack of experience in this field. Usually, *E. coli* is used as an indicator of pathogens in a given matrix. However, several pathogenic microorganisms and eggs of worms will survive longer in human faeces than *E. coli*. Accordingly, other and/or more than one indicator species should be considered in order to guarantee a reliable safety standard. After 11 months of composting at De Ceuvel, the level of streptococci was reduced by log 1.9. This does not meet the WHO recommendation of log 6 reduction by composting.

6.2.3 Urine

Pure urine from a waterless urinal at Café De Ceuvel was used for nutrient recovery. Tomatoes were grown with the recovered fertilisers and tests with pharmaceutical micro-pollutants were performed to investigate contamination of the fertilisers. The concentration of pharmaceuticals in tomatoes was below detection limits (0.02 mg/kg). These levels were far below the acceptable daily intake (ADI), which is 1% of the minimum therapeutic dose. It is therefore possible that tomatoes produced with urine-derived struvite-sorbent fertilisers are safe for human consumption. However, although no bio-accumulation was detected in the tomatoes, this does not preclude bio-accumulation in other parts of the plant, for example the roots or leaves, which were not tested. Since nutrients and other molecules are taken up from soil by the roots, micro-pollutants might accumulate in root biomass. Therefore, further investigation should be carried out into struvite-sorbent fertilisers for root crops, such as carrots or radishes, and leafy vegetables, such as lettuces. The nutrients in biochar-based fertiliser were shown to be less available than zeolite-based fertilisers in the short-term, but could become more available after degradation of biochar.

6.2.4 Life Cycle Assessment (LCA)

Currently drinking water at De Ceuvel is supplied through the public centralised drinking water supply system of Waternet. Possibilities to implement local water collection and upgrading towards drinking water quality were studied. At De Ceuvel, canal water, rainwater and grey water are potential water sources for local drinking water supply. With the performed LCA study the environmental impact of centralised and decentralised drinking water production, specific for the operational aspects, is compared. The drinking water production at Weesperkarspel (Waternet, Amsterdam) was model for a centralised drinking water production, and De Ceuvel was used as model for the decentralised potable water production from canal water. The goal of both systems is to produce drinking water according to Dutch quality standards. The production of decentralised drinking water has a higher environmental impact and corresponds to 0.104 Ecopoints. This is approximately 25% more than the centralised situation (0.0762 Ecopoints). The difference between these two scenarios becomes more significant (60%) when also the distribution network is included in the calculation. The environmental impact is strongly affected by the energy origin. Improvements in energy demand or (green) energy supply can be implemented both at centralised and decentralised scale and as such there is no difference in environmental impact. The environmental impact was assessed per m^3 of drinking water. The fact that less drinking water is used at De Ceuvel does reduce the environmental impact of operations. The impact of infrastructure, especially distribution, is not affected by the use, since the momentary demand when opening a tap determines the design of this infrastructure.

6.2.5 Quantitative Microbial Risk Assessment (QMRA)

Also from a safety perspective, possibilities to implement local water collection and upgrading towards drinking water quality were studied. The proposed treatment system should be capable of producing water that complies to the Dutch drinking water standards with respect to microbial safety, with a maximum risk guideline value of 1 infection per 10,000 persons per year. Chemical contaminants may also be relevant for alternative water supply systems (Etchepare and Van der Hoek, 2015), however in this study the focus was on microbial contaminants since they form an acute health risk. It is possible to produce safe water in a decentralised system and in the case of De Ceuvel local canal water is the best source. However, the QMRA assumes constant performance of the treatment processes at the proposed level and sufficient operation and maintenance. This requires advanced treatment technologies and strict monitoring and maintenance. The latter will be challenging for consumers with limited knowledge of health risk and the technologies (Harvey et al. 2015). Replacement of membranes or UV-lamps which appear to be still functioning may be considered non-sustainable and expensive by end users, thus compromising safety. Therefore, monitoring, operation and maintenance would need to be performed by a specialized company, e.g. Waternet. To reach current drinking water safety standards with point of entry or point of use systems, more sensitive and reliable sensors are needed and human perception and behaviour need to be taken into account. Even though the water treatment technology could produce safe water, current monitoring technology is not capable to guarantee this continuous safety in an independently operated decentralised system.

6.2.6 Financial issues

Decentralised drinking water production is in theory allowed when the following three priorities are fulfilled:

1. The drinking water needs a guaranty that it is safe.
2. It needs to be produced in a sustainable manner.
3. It needs to be produced against acceptable costs.

However, to ensure that the drinking water quality is guaranteed, a comprehensive monitoring program is needed, which will increase the costs, so it becomes difficult to still produce at acceptable costs. Current quality monitoring regulations appear to make decentralised drinking water production 3 to 10 fold more expensive compared to centralised drinking water production. Monitoring of pathogens in raw water, indicator removal and operational conditions to perform QMRA according to the guidelines would also require substantial resources. To reach current drinking water safety standards with point of entry or point of use systems, more sensitive and reliable sensors are needed and human perception and behaviour need to be taken into account. The cost and sustainability of these additional systems including the required monitoring and maintenance (by a qualified company) was beyond the scope of this study, but needs to be addresses in the total feasibility of decentralised solution. Only when the costs for quality monitoring are reduced with about 90%, decentralised drinking water production might be economically more favourable compared to the current costs for centralised drinking water production.

When labour costs for operation and maintenance are minimized by the deployment of volunteers in decentralised wastewater treatment, overall costs can be comparable with centralised treatment, but such a comparison is not completely fair and certainly not advisable from a risk point of view. Furthermore, the current costs for centralised drinking water production and wastewater treatment includes several additional aspects, like costs for environmental protection, research & development and additional tax.

6.2.7 Legislation

Regarding additional involved legislation, De Ceuvel association needed to get the following permits and fulfil other activities concerned to regulation before they were allowed to start building:

1. A change to the zoning plan (bestemmingsplan) for the whole ground;
2. A building permit for each individual boat;
3. A permit to discharge water (disposal of effluent).

Permits 1 and 2 were needed from the municipality (Stadsdeel Noord) and permit 3 was obtained from the Omgevingsdienst Noordzeekanaal (ODNZK), but actually an environmental permit (*omgevingsloket vergunning*) should have been obtained from the Ministry of Infrastructure and Environment. Investigation of the Dutch legislative environment brought additional insights on the right procedure to follow when installing and using Individual Wastewater Treatment (IWT). While the current legislation requires every IWT system (15 small scale biofilters in the case of De Ceuvel) to be monitored 2 times per year on effluent quality, there is still no clear process and agreement for the stakeholders of De Ceuvel project regarding who and how should the quality monitoring of these systems be performed.

6.2.8 User behaviour

Finally, user behaviour and satisfaction were investigated. It is clear that the occurrence of uncontrolled phenomena such as smells and flies are not acceptable for users. It breaches the comfort level of conventional solutions they are used to. When solutions for each of these issues are implemented, the users are as happy with the clean technologies as they are with conventional systems. The first outcome of their feedback is that grey water systems are well accepted among the community, since the removal of the settling drums in Fall 2014. It can be concluded that a regular use of composting toilets is not recommended in the Netherlands, because of discomfort of the users, higher costs and the difficulty to safely reuse the compost. Taken into account the goal of the research at De Ceuvel (local loop closure) and the lack of a sewer connection, the use of composting toilets is understandable.

6.3 Recommendations

The biofilters installed on De Ceuvel site (grey water purification systems) ensure sufficient water effluent quality for the water to be discharged into the ground without threatening the environment, based on Dutch regulation. Still, further research could be conducted on one specific parameter of water quality (Total Suspended Solids) for which some variable results have been obtained.

Concerning toilet waste composting, results on biological indicators show that toilet waste needs to be composted for a longer period of time in order to ensure safe handling and reuse as a soil conditioner. Aside from biological safety, level of metals in toilet waste need to be assessed. In that respect, the analysed toilet waste contains 2 metals (Zinc and Copper) out of the 8 metals regulated by the Dutch fertiliser act. For these 2 detected metals, concentrations vary significantly; while average concentrations remain below regulation limits, some of the maximum values for metal-to-nutrient ratios are above regulation limits. The reasons for this observation are not known and could be further investigated, but also in the surplus sludge of wastewater treatment plants and digested sludge the Zinc and Copper levels are often found to be above the regulation limits. Whether the metals levels would be an issue from environmental, human safety and legal standpoints, if the compost produced from toilet waste were to be reused as a soil conditioner, should also be assessed.

The long-term effects of using contaminated urine-derived struvite-sorbent fertilisers on soil quality should be investigated. It may be necessary to carry out further research in order to determine the indirect risk of using contaminated plant biomass as a feedstock for other purposes, such as compost or animal feed. Further investigation should also be carried out into struvite-sorbent fertilisers for root crops, such as carrots or radishes, and leafy vegetables, such as lettuces. Besides a much larger crop trial, also a broader range of pharmaceuticals are necessary to test the robustness of the preliminary performed experiments.

In addition, feedback from users on De Ceuvel allows for a better understanding of which aspects of the clean technologies are problematic or satisfying. Composting toilets are not well accepted by most of the users. Technical improvements, user-friendly handling and better communication (e.g. operation guidelines) could improve the acceptance, but it is strongly recommended to use other (new) sanitation solutions. Technically local loop-closure is feasible, but user acceptance and especially legislation issues are still challenging. Furthermore, even though the water treatment technology could produce safe drinking water, current monitoring technology is not capable to guarantee its continuous safety in an independently operated decentralised system. However, resource recovery and recycling from waste streams is an important issue in the needed circular economy and several promising options are available. Nevertheless, the experiences on De Ceuvel showed that it is currently not easy to apply complete local loop-closure in The Netherlands, but more research and experience with bigger, more representative projects, is needed (e.g. new sanitation pilot in Buiksloterham). Important issues regarding responsibilities, user-acceptance, health and safety risks, sustainability and cost reduction should be taken into account.

6.4 Conclusions

It can be concluded from this study that decentralised drinking water in an urban environment as De Ceuvel, with a temporary office function, is less sustainable and more costly than a centralised system and that the same level of safety cannot be guaranteed. However, when connection to a centralised system isn't possible or only at high cost, decentralised solutions can provide an alternative. Decentralised drinking water treatment systems generally have a higher energy requirement per cubic meter of water produced due to the small scale. By reducing the amount of water used, the total use of energy and thus environmental impact will be reduced. When sufficient, sustainable energy is available the total environmental impact and total cost can remain low. For large scale systems, reduced water use has limited effect since its costs and environmental impact depend more on the fixed assets.

Individual wastewater treatment as performed on De Ceuvel is more costly than current centralised wastewater treatment in The Netherlands. Nevertheless, grey water can be treated with low-tech biofiltration in individual water treatment systems to achieve sufficient water quality for discharge into the ground, based on Dutch regulation. The decentralised system at De Ceuvel allows for direct reuse of resources by e.g. composting faeces and recovering nutrients from urine. Composting of faecal matter in the Netherlands requires over 11 months, after which *streptococci* reduction still did not meet WHO recommendations. Short term experiments showed that urine-derived struvite is an excellent fertilizer. Struvite from urine spiked with pharmaceuticals didn't lead to detection of pharmaceuticals in tomatoes. However the long-term effects of using urine-derived struvite-sorbent fertilisers on soil quality should be investigated. Research should focus on uptake of contaminants by root crops, such as carrots or radishes, and leafy vegetables, such as lettuces. The alternative of using struvite to grow contaminated plant biomass as a feedstock for other purposes, such as compost or animal feed should also be investigated for long term health risks. Struvite-sorbent fertilisers could be developed further to optimize nutrient recovery from urine. Users seem to accept these initiatives if the level of comfort is comparable to conventional systems. Health and safety risks and related responsibilities for both water loop-closure and resource recovery are points of concern for decentralised systems, which cannot be solved by technology alone. New technologies need to address user behaviour and awareness to achieve safe decentralised systems. Legal and institutional aspects regarding local water treatment and loop-closure are under development and currently not always clear. Technically local loop-closure is feasible, and technological developments can shift the conditions at which decentralised systems are the preferred option in terms of costs and sustainability in the long term. Future research and experience with bigger, more representative projects addressing technology and user behaviour can use and further develop the decentralised concepts from the current study.

Overall, aspects that could be beneficially applied in future decentralised concepts can be identified from this TKI project and currently include:

- Site specific risk- and sustainability assessment of decentralised systems and loop-closure are needed to make appropriate choices for implementation.
- No decentralised drinking water production in an urban environment as De Ceuvel.
- No application of composting toilets, but more comfortable (new) sanitation solutions.
- Separated collection of wastewater streams and treatment has potential for e.g. direct reuse of resources.
- There is interest in rainwater use for e.g. flushing toilets, gardening, showering, and dish washers.

7 References

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Appendix I Safe handling of dry toilet waste

Conclusions and recommendations student project (Academic Consultancy Training of Wageningen University)

The following conclusions and recommendations are directly copied from the final student report, which has been prepared with guidance and advice from the TKI project team.

Conclusions

This project has aimed to find an advice on reusing valuable components of dry toilet waste, originating from the CTP de Ceuvel, as safely, low-costly and sustainable as possible. In this conclusion, the answer on the different sub questions will be listed to show how FertilOO came to its advice. The subsequent recommendations can be found in the next section.

1. Which components are valuable in (dry) toilet waste and which human pathogens and toxins are major (safety) risk factors? Human excreta contain valuable potassium, phosphorus and nitrogen that can be very useful in reusing the human waste as compost. Urine contains a higher concentration of these nutrients than faeces. Heavy metals are not considered a risk, since animal manure contains higher heavy metal concentrations than human faeces and can still be used for composting purposes. More pathogen species are excreted via human faeces than via urine. Different bacteria, viruses, protozoa and helminths can pose a threat to human health if someone is infected by wrong exposure to the human waste or compost. Especially helminths can pose a risk, since the eggs of Ascaris are able to survive the longest in human faeces of the pathogens studied and even longer in soil.
2. How to implement and improve techniques that modern society uses to make toilet waste usable to CTP De Ceuvel and how can the quality be controlled? There is a large variety of techniques available in modern society that range from high-tech to low-tech technologies and processes. Specifically evaluated are the technologies of the urine diverting dry toilet (UDDT) and the process of vermicomposting. The installation of a UDDT requires the urine and faeces to be treated separately. Vermicomposting is a process that can be used with source separating technologies as well as mixed source technologies. Learnt from practice in Anastasiadorp (Anastasia and Dorp, 2015), two containers of approximately 5 m^2, with a height of 1.5 m are required to compost the faeces at CTP De Ceuvel for 2 years. Especially with vermicomposting the proceedings need to be reported with use of these forms where the time and layer that has been added are noted. After two years, the compost is considered to be safe to use. The quality of the excreta can be controlled through measuring for indicator species in the compost.
3. What are current legislations for the use of animal manure as a fertiliser/soil conditioner and how could it be applied to human faeces? Legislation on animal

manure is mainly focussed on the heavy metals that are present in animal manure. Animal manure can be used if it is treated biologically, chemically or with heat. It is difficult to apply these regulations to the reuse of dry toilet waste because animal manure does not take pathogens into account. Pathogens are a bigger concern than heavy metals in human waste. Human excreta contain more pathogens than animal manure (Niwagaba, 2007) (see Appendix Table 6). Another waste stream that does contain human waste is sewage sludge. Current legislations on sewage sludge are stated in the Dutch waste management plan (Landelijk afvalbeheerplan). It states that it can only be treated by thermal processing, gasification and hydrostab. With the thermal processing, the nutrients are still available in the ash, but the nitrogen will be lost about 10 % to 50 % during this process, because of the high temperature, pH and high aeration (Jönsson et al., 2004). Other options for legally using human waste compost is to apply for an `End-of-Waste'-status.

4. To what extent are (safety) risks communicated to the users of CTP De Ceuvel and to what extent are they aware of the risks in relation to dry toilet waste? From interviews with the users of CTP De Ceuvel it became clear that users do feel responsible for maintaining their toilet and handling the waste. However, they feel responsibilities for maintenance of bigger issues, education and general help lie somewhere else. They do feel that Metabolic has tried to empower them, yet at the same time they think this was not done successfully and could be improved.

Recommendations

There are several suggestions to improve the current safety and composting processes at CTP de Ceuvel in the most sustainable, low-tech, low-cost way. To start with, the addition of pieces of paper instead of wood chips are advised, in order to lower the lignin content that is hard to degrade biologically and to repel flies, without losing the advantage of enhancing the C/N ratio of the starting substrate. Addition of plant ash and/or lime to increase the pH can be considered as well, since they will speed up pathogen die-off.

Another improvement would be to introduce vermicomposting with backslashing at the centralised treatment point. It is a pathogen reducing, low-cost, fast, energy saving, easy to handle, cheap and zero-waste process in which earthworms are able to convert new compost, combined with old compost, into soil conditioner and/or fertiliser. Backslashed vermicompost can be accomplished with excreta, as well as with faeces only. The size of the two containers that will be required are difficult to calculate, since the compost subsidence rate is difficult to determine. However, based on the size of the vermicomposting system we have seen in Deventer[4]. To make sure that the compost produced is approved to use, it is advised to apply for an `End-of-Waste' status that will transfer humanure from a `waste' status to a `product' status, whereafter the product can be used with legal approvement. We advise to request this approval specifically for CTP de Ceuvel via the province Noord-Holland and for `humanure' in general via the government as well. Moreover, a `*Keurcompost*' certificate can be applied for, which if approved will show that `humanure' is safe and profitable to use. Through these different applications, insight can be gained on the achievability of using `humanure' in the future.

Regarding safety risks involved at CTP de Ceuvel, it is recommended to periodically measure the concentration of different pathogens. Identify beforehand the pathogens present in the

[4] 2/3 of the normal amount of poop because of working instead of living. In Anastasiadorp, the sizes were 1 m * 1 m = 1m^2 for approx. 6 people; In CTP de Ceuvel, live 50 people. This means that (33/6) * 1 m^2 = 5.5 m^2 is needed.
From experiments at Anastasiadorp it is estimated that the size per container should be 5.5 m^2 and a height of 1.5 m to accommodate vermicomposting for CTP de Ceuvel for a two year time span.

excreta, in order to know what to look for in the compost. Furthermore, safety of the excreta can be increased when people follow all technical and behavioural measures that are prescribed.

Communication with local businesses at CTP de Ceuvel must be improved in order to guarantee handling safety. Using a sound communication plan and frequent face-to-face communication for updates and questions can help with this. It is also recommended to create an A4-sized manual with the most important do's and do not for using and maintaining a composting toilet and post them in every toilet stall, as was done in the Skaneateles project (Dimp and Moran, 2014). To quickly improve the user experience at CTP de Ceuvel, the tumbler should be relocated to the other side of the terrain. This may also help to prevent or at least minimize the misuse from visitors (Visitor, 2015). Furthermore, another information day or workshop to increase awareness might be considered.

Provision of gloves and face masks at the tumbler, in case people forget to put them on, is advised. When users take their bucket out they can at least put a face mask on when opening the tumbler. Regarding the techniques and composting processes, some factors for wrong handling measures could be taken into consideration to ensure a safe end product even if not all measurements are taken (Peasey et al., 2000). Finally, it should be taken into account that it may take several years for behaviour to change and before it can truly be said that a project is successful.

As a more drastic change, it is proposed to the current system is to exchange the current non-separating dry toilet for a urine diverting dry toilet (UDDT), because urine is almost sterile and contains most of the nutrients in excreta. This way, the urine can be stored for 12-26 weeks instead of a treatment of 1-2 years before use. BioLan UDDT's are recommended because of high chance of eliminating possible flies from the faeces and the prevention of odours by a ventilation pipe and no electricity is needed for operating this toilet. What needs to be taken into account is that beddings should be added after every defecation; no other covering material is needed (?). To make this system work, besides two containers for vermicomposting, two containers for urine storage are required. Two urine tanks of about 7 m^3 each should be used, where the urine can be stored up to 6 months to make it free of pathogens[5] . After 12-26 weeks the urine can be used as a fertiliser when diluted with water. Meanwhile the other urine tank can then be filled until it is full and can be stored for maximally 6 months as well.

The most important limitations and solutions for the current situation at CTP de Ceuvel as summarised in the table on the next page (Table 31). Finally, all that can be said is that literature and theories can only give you so much information, but in the end the only way to find out what really works, is by experimenting. We therefore encourage CTP de Ceuvel to keep doing this.

[5] The size of this tank is calculated by using the formula (2/3) * 1.2 L/p/d * (365/2) d * 50 p = 7300 L = 7.3 m^3 , where it is assumed that people will excrete 2/3 of its total urine production (1.2 L/day according to (Tilley et al., 2014)) at CTP de Ceuvel during half a year . Roughly 50 persons are estimated to make use of these toilets. All parameters are over-estimated in order to make sure that the tanks will be large enough.

TABLE 31 MOST IMPORTANT LIMITATIONS AND SOLUTIONS FOR THE CURRENT SITUATION AT CTP DE CEUVEL

Current situation	Limitation	Effect of limitation	Solution	Effect of solution
Composting chamber toilet	Relatively sterile, nutrient rich urine cannot be used as fertiliser separately	Urine needs to be treated for 1 to 2 years	Urine diverting dry toilet	Urine needs to be treated for 12-26 weeks
Instruction on toilet use absent in situ	Less involved locals and guests lack knowledge on proper use of the toilet	Sub-optimal pre-composting process	Facilitate convenient user instructions at every toilet	More optimal use of toilet system
Wood chips as additive in toilet	Contains lignin	Limited biodegradability	Add (toilet) paper (>C/N ratio), plant ash (>nutrients, trace elements) and/or lime (>pH)	Enhanced composting process and enhanced plant growth when applied
Tumbler	Aeration and drying only	Limited pathogen reduction (from experience)	Two tanks with backslashed vermicompost	Extensive pathogen reduction (from literature)
Tumbler	Necessary to open, turn and empty the tumbler	Infection risk through aerosolisation (without mask)	Two tanks with backslashed verrmicompost	Lower infection risk through aerosolisation
Location centralised treatment	Near Café de Ceuvel	Infection risk for guests through aerosolisation and 'walk of shame' with full toilet buckets for locals	Relocate centralised treatment to the other side of the area	No risk for guests and less shame for locals
Deficient use of protection material	Gloves and face masks are insufficiently available and/or worn when needed	Infection risk through touch and/or aerosolisation of pathogen containing excreta	Supply boats and centralised treatment point with sufficient protection material	Lower infection risk
Deficient communication plan	Less involved locals and guests lack knowledge on proper use of the toilet and treatment system and who to turn to when encountering problems	Sub-optimal composting process, health risks, sub-optimal troubleshooting and ambivalent responsibility	Provide convenient user instructions on paper at every toilet and at the centralised treatment system, have more face-to-face contact with users and organise an information day	Faster troubleshooting, higher quality of the product, more satisfied users

Appendix II Dutch regulation regarding Individual Wastewater Treatment (IWT)

Based on the Commissie Integraal Waterbeheer report ‘Individuele Behandeling van Afvalwater IBA-systemen’ (1999), which content is reproduced in Dutch below, the effluent of individual wastewater treatment systems has to be analyzed twice a year.

“3.6.3 Wat en hoe wordt gecontroleerd?

Bij niet gecertificeerde IBA-systemen wordt de zuiverende werking van het systeem met grotere regelmaat gecontroleerd. Bij nadere eis of in vergunningvoorschriften zal de lozer bovendien een meetverplichting opgelegd krijgen. Een lozer dat een gecertificeerd IBA-systeem gebruikt krijgt geen eigen meetverplichting. Zie voor de frequentie van monstername door de lozer hoofdstuk 4, paragraaf 4.7.

Het is mogelijk dat feitelijke controle van de werking van het IBAsysteem door het jaar heen plaatsvindt door bedrijven gespecialiseerd in de aanleg en het onderhoud van (gecertificeerde) IBA-systemen of door de lozer. De controlegegevens worden bijgehouden in een logboek. In het logboek zijn gegevens terug te vinden over onderhoudcontroles, aard, data en herstel van storingen, afvoer van drijvend materiaal en slib. De handhaver zal bij controle uitgaan van de gegevens uit het logboek. Het effluent wordt gecontroleerd via steekmonsters. Indien een gecertificeerd IBA-systeem in gebruik is zal bij controle door gemeente of waterschap niet standaard een steekmonster genomen worden en op parameters worden getest. Bij omvangrijke bodemlozingen worden ten behoeve van de tweejaarlijkse keuring van het IBA-systeem monsters genomen. Indien geen gecertificeerd IBA-systeem is geplaatst, wordt van de lozer verwacht dat hij zelf het effluent via steekmonsters laat controleren. De wijze waarop monsters worden genomen en gecontroleerd vereist de goedkeuring van het bevoegd gezag.“

The parameters to measure are stated in the Law Decree for discharge outside the common established systems (Wet Besluit lozen buiten inrichtingen, artikel 3.6, Lozen op of in de bodem of in een aangewezen oppervlaktewaterlichaam). See Tabel 1and Tabel 2 on the next page for the exact parameters.

TABEL 1 WATER DISCHARGE REQUIREMENTS – DUTCH ORIGINAL VERSION

	Lozen op of in een aangewezen oppervlaktewaterlichaam		**Lozen in een niet aangewezen oppervlaktewaterlichaam**	
Parameter	**Representatief etmaalmonster**	**Steekmonster**	**Representatief etmaalmonster**	**Steekmonster**
Biochemisch zuurstof verbruik	30 mg/L	60 mg/L	20 mg/L	40 mg/L
Chemisch zuurstof verbruik	150 mg/L	300 mg/L	100 mg/L	200 mg/L
Totaal stikstof	x		30 mg/L	60 mg/L
Ammoniumstikstof			2 mg/L	4 mg/L
Onopgeloste stoffen	30 mg/L	60 mg/L	30 mg/L	60 mg/L
Fosfor totaal	x		3 mg/L	6 mg/L

TABEL 2 WATER DISCHARGE REQUIREMENTS – ENGLISH TRANSLATION

	Discharge into the ground or in a defined surface water body		**Discharge in an undefined surface water body**	
Parameter	**Representative sample**	**Grab sample**	**Representative sample**	**Grab sample**
BOD	30 mg/L	60 mg/L	20 mg/L	40 mg/L
COD	150 mg/L	300 mg/L	100 mg/L	200 mg/L
TN	x		30 mg/L	60 mg/L
NH4-N			2 mg/L	4 mg/L
TSS	30 mg/L	60 mg/L	30 mg/L	60 mg/L
TP	x		3 mg/L	6 mg/L

Appendix III Small-scale mobile wastewater treatment system by AWWS

Introduction

Many places around the world are not connected to the grid of sewerage pipes for the safe discharge of their wastewater. Furthermore, in many European countries, where sewerage ground pipes are present, these are over 50 years of age and in need of replacement or reparation. This entails large investment costs. For example, the necessary investments for the USA are calculated at $500 billion to be invested in the next 20 years. AWWS believes that decentralised wastewater treatment units are the just answer to these present-day and upcoming problems. Decentralised units largely eliminate extensive piping networks and hence excluding the need for the respective investments. Smart engineering of these units into containers or on trailers enables their easy installation all over the world.

De Ceuvel is an interesting site since it comprises only offices, but no households. Furthermore, the wastewater consists of only grey water due to the implementation of composting toilets. The lack of showers and washing machines extremely lowers the on-site water consumption and respective (grey) wastewater production. It is agreed that for these low volumes, AWWS technologies are too complex and expensive as compared to the low-tech and low-cost biofilters used currently on-site. However, household communities, or combinations of households and business locations, touristic places such as hotels, or events like festivals, often produce higher volumes of wastewater that can consist of only grey water, only black water (i.e. toilet water), or (and most probably) a combination of both. For these situations, AWWS developed a small-scale mobile wastewater treatment unit.

Small-scale mobile wastewater treatment unit

In the AWWS small-scale mobile wastewater treatment unit (Figure 19) the water is first biologically treated in a moving Bed Bio-Reactor (MBBR). Micro-organisms adhered to carrier material remove the organic load in the water. The organic load can be human excrements, soaps, etc. The micro-organisms use the organic load for their own growth, meanwhile converting it into CO_2 and new biological cells. Superfluous biomass coming off the carrier material is led to the second step: the sludge-water separator tank. Here, the sludge is separated from the water using AWWS advanced microbubble concentrator technology. The latter ensures higher dry matter contents of the removed sludge (60 g L^{-1} versus 15 g L^{-1} in conventional techniques). This results in 4 times more concentrated sludge and hence, lower sludge volumes to be handled for discharge or further processing (e.g. energy and nutrient recovery). Also, no membranes are used in this separation step, eliminating the risk of clogging and service-stops. The obtained effluent quality comprises to the European legislation for surface water discharge.

The small-scale wastewater treatment unit of 2.2 m (height) by 3.3 m (length) by 1.6 m (width) fits on a trailer for easy transportation. This mobile unit can be equipped with solar panels (such as the ones produced by Metabolic) to ensure its entire off-the-grid functioning. When employing the unit for the treatment of shower water (for example on festivals), the daily amount of grey water produced by 6 showers can be handled. This is equivalent to 43

m^3 of water per day. The unit produces only 25 L of sludge per day. The sludge needs to be collected in a separate container and can safely be disposed of by a waste collector.

Although this wastewater treatment unit was built to handle only shower water, it can handle all combinations of black and grey water. The water volumes that can be treated depend on the organic load of the influent. This is because the COD (chemical oxygen demand, a measure for the chemically oxidizable organic load) to be converted by the micro-organisms will be higher for black water, or a mix of black and grey water, than for shower water only. Furthermore, the system is easily scalable up to 1,000 PE (person equivalents) to treat 140 $m^3\ d^{-1}$. AWWS has experience building these larger units into containers. An asset for their transportation and easy installation all over the world.

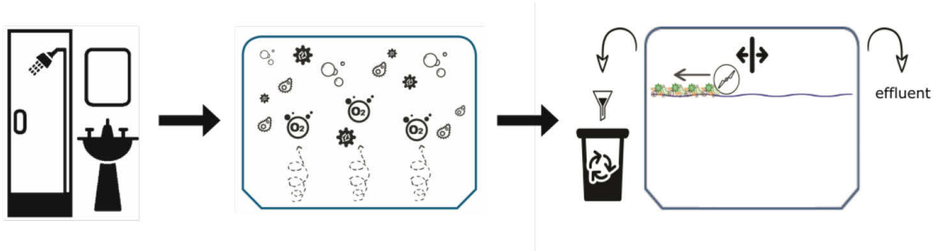

FIGURE 19 SCHEMATIC OVERVIEW OF THE SMALL-SCALE MOBILE (GREY AND BLACK) WASTEWATER TREATMENT SYSTEM BY AWWS