AQUA-PURIFIER PHYTO-FAÇADE SYSTEM

'Exploring the contribution of an active green façade in the purifying of MarineTerrein water'

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Abstract

'Phytoremediation is the use of plants and their associated microbes for environmental clean-up'(Pilon-Smits, 2005). It is a natural, passive and efficient way of cleaning contaminated soil, water, and air. Every year, there are reports of contamination of swimmers due to the contaminated canal water round the Marineterrein in Amsterdam. The goal of this research paper is to investigate the different technics of water phytoremediation susceptible to be used to passively and actively purify the Amsterdam canal water and determine their applicability on and around a building. The founding of this research will be used to develop a new type of green façade that can remedy to the major problem of water pollution around the MarineTerrein in Amsterdam.

Keywords: *Phytoremediation, Water pollutants, Constructed Wetlands, Helophyte Filters, Grey wastewater, Hydraulic Conductivity, Macrophytes Plants.*

1. Introduction

Clean water has become a rare commodity worldwide. Country and cities are facing new challenges among each water pollution caused by wastewater. By wastewater, we mean water 'that carries wastes from households, industries, institutions, hospitals, and agriculture'(see appendix)(Nanninga, 2011).
In the case of Amsterdam or the Netherlands in general, water has a prominent place in the urban tissue mainly due to its omnipresence. As the water used to and still contribute to the economic development of Amsterdam and gives a unique identity and attractiveness to the city, it very important to preserve, protect and the canal water using sustainable means (Evie Cox, 2016). Amsterdam canals are well known to be polluted with all kind of pollutants mostly coming from human activity. Waste such as plastic bottles, bicycles, etc., human or animals excreta, or simply navigate activities to make the water of the canal now suitable for swimming especially for regular swimmers. Nowadays canal water in Amsterdam is mostly polluted by sewage wastewater which overflows in the canal especially after heavy rains (see figure 1). The wastewater caused by domestic activities (*domestic wastewater*) can be subdivided in *black wastewater* (containing biological and chemical wastes), *grey wastewater* (from kitchen, shower, bath, sinks and laundry activities) and *municipality wastewater* (grouping domestic and industrial wastewater. The black wastewater, contaminated largely by human excreta, can be subdivided into brown wastewater (containing fecal matter and toilet paper) and the yellow wastewater (containing urine) Nanninga (2011).

Except for the water pollution issue, the city of Amsterdam seems to have a lack of natural swimming spots in the city center. All the official swimming spots are situated on the outskirts of the city far away from the city center. The all 24 official swim spots (Sloterplas, Gaasperplas, Amsterdamse Bos (speelweide), Nieuwe Meer en de Oudekerkerplas, etc.) are situated outside of the city borders (see figure 2). 'For people living in the city center, it takes some effort to reach these spots'(Evie Cox, 2016). Building an official swimming spot on Marineterrein will not only solve this lack of swimming spot in the city center but also will increase its attractiveness towards tourists. Besides that, using plants to clean water canal water will be a good opportunity for the city of Amsterdam to be more sustainable in its way of dealing with water pollution.

The use of plants (with their pollutants retention capacity) on and around building facade to clean canal water is the appropriate solution to the water pollution issue in Amsterdam (see figure 3). This leads us to the main question of this research paper:

How to implement *phytoremediation on and around a new building* in order to *make canal water suitable for swimming*?

The main objective of the research paper is to find the right knowledge regarding water phytoremediation and how those findings can specifically be implemented on Marineterrein basin to make that water suitable for swimming. At the end of this project, a new façade-system will be developed on a new building to show the possibility of using green to remediate water in a very dense urban area.

My research approach is first to deepen the existing technics which remediate wastewater using plants, the way they are constructed and maintained. Being aware of their performance and their effectiveness can substantially help to minimize the maintenance and energy costs. The second part of my approach is to research how those phytoremediation technics can be implemented on and around a building on that specific area of Marineterrein. This means that the water pollution stand has to be determined so that the right plants and the right type system can be selected.

2. Water remediating technics

2.1. Phytoremediation

According to the United Nation Environment Program (UNEP), phytoremediation is 'the efficient use of plants to remove, detoxify or immobilize environmental contaminants in a growth matrix (soil, water or sediments) through the natural biological, chemical or physical activities and processes of the plants'(EPA, 2017). Phytoremediation is a generic term that refers to a group of technologies used by plants to remedy the organic and inorganic contamination of soils, water, and air. Those technologies depend on the type of contaminants, type of plants and the process used to implement them. Phytoremediation technologies can be thus subdivided into 6 types (EPA, 2017):

- *Phytodegradation*: use of plants to uptake, store and degrade contaminants within its tissue
- *Phytostimulation or rhizodegradation*: use of rhizospheric associations between plants and symbiotic soil microbes to degrade contaminants.
- *Phytovolatilisation*: use of a plant's ability to uptake contaminants from the growth matrix and subsequently transform and volatilize contaminants into the atmosphere.
- *Phytoextraction*: use plants to absorb, translocate and store toxic contaminants from a soil matrix into their root and shoot tissue.
- *Rhizofiltration*: use of roots to uptake also store contaminants from an aqueous growth matrix.
- *Phytostabilisation*: plant-mediated immobilization or binding of contaminants into the soil matrix, thereby reducing their bioavailability (See figure 4).

Considering that the main goal of the graduation project is mainly about water (and the bottom soil to some level) the phytoremediation will be limited to rhyzofiltration and phytostabilisation. Compare to mechanical water purification systems, phytoremediation is a passive process but the in term of effectiveness is almost similar.

2.2. Constructed wetlands, a passive solution

Rhizofiltration refers to the use of wetlands for retention of pollutants from water (Mackova et al., 2006). This absorption capacity of plants occurs in its roots which makes it easier to control and to implement in different ways. In their second edition *Treatment Wetlands*, Kadlec and Wallace(2009, Nanninga, 2011) distinguish 3 types of constructed wetlands:

- *Free water surface (FWS) wetlands*: looking like natural wetlands such as marshes or morass, they are designed areas of open water containing floating and emergent plants. 'Depending upon local regulations and soil conditions, berms, dikes, and liners can be used to control flow and infiltration. As the wastewater flows through the wetland, it is treated by the processes of sedimentation, filtration, oxidation, reduction, adsorption, and precipitation'(see figure 5) Kadlec and Wallace (2009).

- *Horizontal subsurface flow (HSSF) wetlands*: consist of a gravel or soil beds planted with wetland vegetation. In HSSF system, wastewater always flows below the bed's surface, entering from the inlet goes through the roots and rhizomes of plants and flows out through an outlet. The fact that wastewater beneath the surface flows, helps to minimize its contamination by human or pathogenic organisms. 'Properly operated HSSF wetlands do not provide suitable habitat for mosquitoes'(see figure 6) Kadlec and Wallace (2009).
- *Vertical subsurface flow (VSSF) wetlands*: distribute 'water across the surface of a sand or gravel bed planted with wetland vegetation. The water is treated as it percolates through the plant root zone. Biosolids dewatering wetlands can be thought of as a type of VSSF wetland system.'(see figure 7) The VSSF wetlands can be subdivided into 2 types variations: the pulse loading type and the tidal flow type. The pulse loading system used 'surface flooding of the bed in a single- pass configuration similar to the one used in intermittent sand filters (see figure 8). The tidal flow system consists of a fill-and-drain system meant 'to treat high-strength wastes and to oxidize ammonia due to its limited oxygen transfer (Kadlec and Wallace, 2009).
- *Hybrid constructed wetlands*: To increase the removal efficiency of a constructed wetland, those 3 types of wetlands can be combined in different cells order. The most common is system is a VSSF stage followed by HSSF wetland cells, 'His alternative is a hybrid system made by a horizontal flow bed followed by VSSF wetland cells'(see figure 9).

Different wetland types used different type plants (free-floating plants, rooted floating plants, submerged plants or emergent plants) and its associated microbes and organisms to absorb and degrade the pollutants. For example, an FWS system can have the 3 type plants while the HSSF and the VSSF systems only the emergent plants have. This is, of course, due to their compositional density and the water flow which do not allow floating and submerged plants(See figure 10 & 11). Besides those aquatic vascular plants, wetlands also contain large varieties of aquatic organisms such as filter feeders (organisms, such Quagga mussels, filter water for nutrition) and aquatic macrophytes (Evie Cox, 2016). Compared to the HSSF system, the VSSF one required more hydraulic installations and is more effective in the removal of organic than the suspended solids. For both, they are direct effective after their construction and we don't have to wait for plants to grow compared to the FWS System.

VSSF Treatment Wetlands Advantages	HSSF Treatment Wetlands Advantages
• Lower footprint than FWS wetlands. • Aerobic reaction kinetics if fully drained. • Organic removal / Nitrification. • Efficient suspended solid removal – high-level filtration. • Ability to incorporate additional media types to provide enhanced treatment (e.g. zeolite, activated carbon). • Good for applications where the public cannot be excluded as wastewater is kept below ground. • Don't have to wait for plants to grow before treatment is provided.	• Lower footprint than FWS wetlands. • Low hydraulic requirements – flat hydraulic grade line through treatment train. • Anoxic environment for denitrification. • Suspended solid removal. • Good for applications where the public cannot be excluded as wastewater is kept below ground. • Don't have to wait for plants to grow before treatment is provided.

(Source: www.waterandcarbon.com)

2.3. Macrophytes and associated microbes

Helophyte filters system (a type of constructed reed bed systems/wetlands) are watertight basins in which macrophytes grow. Macrophytes are plants that grow in or near water and existing different forms (emergent, submerged or floating) and includes helophytes ('plants that grow in the marsh, partly submerged in water, so that it regrows from buds below the water surface'(Wikipedia, April 2014)). 'Their roots and differentiated tissues may be emergent (cattails, bulrushes, reeds, wild rice), submerged (water milfoil, bladderwort) or floating (duckweed, lily pads)'(Elizabeth Tilley, 2014). 'Aquatic macrophytes are aquatic vascular plants, aquatic mosses, and larger algae with tissues that are easily visible'(Evie Cox, 2016). Combined with aquatic filter feeders such mussels, an artificial ecosystem (specific for Marineterrein) can be created to target these specific water and soil type of pollutants. Finding the right plants to remediate specific pollutants, is the key to ensure the success of the helophyte filter system.
Macrophytes such have *Ceratophyllum demersum* have the ability to uptake 70% of lead (or zinc, copper) metals present in the soil. *Dreissena bugensis* mussel (quagga) are able to remove fecal bacteria such as *Escherichia coli* from the water surface while grazing on *Cyanobacteria* (blue-green algae) and phytoplankton. They execrate many nutrients which can cause an increase in other bacteria. Combining them with other macrophyte plants helps to decrease the nutrients and keeps the water cleaned (Evie Cox, 2016).
The proportion in which macrophytes and mussels are used is, of course, decisive to ensure the effectiveness of the helophyte filter systems. As mentioned, the types of growth forms (VSSF, HSSF or FWS) plays also a big role in the choice of plants and ensure the efficiency of the water purification system.

3. Water quality issue on Marineterrein

In 2016, a group of students of University of Wageningen has done a research about the water quality on Marineterrein to look if the basin could become an official swim spot. Every two weeks they took samples and measured the quality of the water (see figure 12). The results out of the measurements show high concentrations of fecal bacteria (E.coli and intestinal Enterococci) due to the overflows of the sewage system in the canals especially after heavy rains (see table 1 & figure 13). This fecal pollutants from human or animal origins represent health risks for swimmers, especially for children, elderly and pregnant women, and can cause diseases such as Gastrointestinal disturbances, ear infections, etc. Besides the water, the soil of water bottom seems to be heavily contaminated by chemicals and heavy metals such lead (due to the build of IJ-tunnel in 1962) or tar and mineral oil (caused by shipyard activities through years). Note that the aquatic sediment of the basin used to be polluted by all kind of debris (floating, emerged) but they have been removed by Waternet responsible of water quality in Amsterdam (Evie Cox, 2016).
In the 2040 vision on water use, Amsterdam municipality wants to make the waters more accessible and livable for its inhabitants. 'The goal is to increase the number of swim spots, and recreational parks next to the water, while improving and monitoring the water quality throughout the city'(Evie Cox, 2016). Therefore, to tackle this water pollution issue, specific plants have to be chosen according to quoted above types of pollutants.

4. Performance and efficiency

The performance of constructed wetlands depends on many things. As Kadlec and Wallace (2009) stated it well, 'the success or failure of a treatment wetland is contingent upon creating and maintaining correct water depths and flows. Hydrologic conditions also influence the soils and nutrients, which in turn influence the character of the biota. Flow and storage volume determine the length of time that water spends in the wetland, and thus the opportunity for interactions between waterborne substances and the wetland ecosystem. The ability to control water depths is critical to the operation of treatment wetlands'. To ensure a better controllability of the whole system, extra mechanical means are needed to control

and maintain the hydraulic regime of the whole system and avoid problems such flooding of the inlet zone of an HSSF or simply it's clogging(Kadlec and Wallace, 2009).
After while in use, the efficiency of a constructed wetlands (especially of an HSSF) can affect by blocking which can occur in the system and influence the hydraulic conductivity of the clean bed. This clogging of the clean bed is, on short-term, caused by the loss of its porosity primarily due to the grow of plants in the upper regions of the bed and the increase of the microbial biomat formation in the inlet region of the wetland bed (their concentration seems to be higher near the inlet than far away from it) (see figure 14). On the long-term, the decrease of hydraulic conductivity of the bed is mainly due to 'deposition of inert (mineral) suspended solids, accumulation of refractory organic material, and formation of insoluble chemical precipitates' (see figure 15)(Kadlec and Wallace, 2009). The type of soil plays a role in the clogging of HSSF systems, instead of using fine soils as a medium (like the early systems), they use gravel in a horizontal surface (instead sloped which was used till 1980's) to prevent the clogging and increase the permeability of the bed. Also, the depth of water seems to have an influence on the hydraulic conductivity in the inlet region, thus on the efficiency of the constructed wetland (see figure 16)(Nanninga, 2011).
To prevent a blocking due to a high solid loading, it is important to ensure pre-treatment of the wastewater (e.g. grey wastewater) before it enters the Sub Surface wetlands system. This can also be achieved by ' by incorporating 'resting' periods within the regular operation to enable organic particles within the media to mineralize'(Group, Unknow). As the composition of the wastewater may differ per country, per location or per period, it is crucial to customize the design and construction to the need of a location to ensure an effective and performing constructed wetland while including its maintenance (Nanninga, 2011). An HSSF system has an advantage of being able to operate under colder conditions than the FWS system because of the ability to insulate the top which can help to prevent clogging of the bed during the winter (Kadlec and Wallace, 2009).
In the case of Marineterrein basin, the efficiency of constructed wetlands depends largely on the coverage of plants in the basin. The fact that the Marineterrein is not a closed-off body from the Amstel river, will have an impact on the effectivity of the plants. Therefore the phytoremediation of Marineterrein water must take place in enclosed water bodies (to prevent any external contamination) to ensure the effectiveness of plants (and associated microbes) and the efficiency of the wetland system (Evie Cox, 2016).
To determine the efficiency and performance of the constructed wetlands, a method of measurement must be established to ensure good water quality and thus safety the of swimmers in Marineterrein. In case of the design project, two types of water will be treated: the existing water of Marineterrein basin intend to be used both swimming pools and the grey wastewater of the building itself intend to be cleaned before its reuse and/or before flowing into the Amstel river.
'The substances in urban wastewater (especially in the grey wastewater) differ at different time periods and that a seasonal, weekly, daily and diurnal variations can be seen.' This makes difficult to get reliable measurements. According to T. Nanninga (2011), a high frequency of collecting samples for measurements (before and after phytoremediation) may be the best way to measure the efficiency of a system but that the required financial resources make it not feasible on the long term. He, therefore, advocates for a 'continuous sampling' methodology depending on the intended quality of the water (aim) and its validity through time (see table 2). For grey wastewater, he proposed a flow-proportional continuous sampling as a method of analysis meanly because of it is produced in peak flows and its high variation in characteristics. For the swimming pool water, a time-proportional would be the right method to measure water quality seen that water is meant for constant discharges (Nanninga, 2011).
The efficiency of wetlands in the removal of wide range pollutants depend on the type of plants but above all on the type of pollutants (see table 5). In some case, they can even act as sources of pollutants. Some wetlands have shown the ability to remove 'Cr, Cu, Pb, Ni and Zn, but also negative removal efficiencies of -84% for Fe and -294% for Mn. Therefore, wetlands generally act as sinks of pollutants, but can also act as sources.' In short, the efficiency of a constructed wetlands depends on its size and structure (e.g. availability of binding sites for the pollutant, presence of appropriate micro-flora and plant species) (Mackova et al., 2006).

5. Implementation

The implementation of the wetlands technologies on Marineterrein has two main objectives. The main objective is to purify basin water in order to fit the requirements of swim regulations. The second objective is to recycle the wastewater of the building. This implies two different ways of implementing on and round a building.

In the case of a natural swim spot, different options of hybrid systems are possible. These options will depend on the amount of the water to purify and the time needed to clean. HSSF wetlands are meant to treat primary effluent prior to either soil dispersal or surface water discharge' (see figure 17). To create a conducive environment for aquatic vascular plants and organisms, modifications must take place on the basin to create artificial habitats for them. As the actual basin 'is too deep for the natural growth of macrophytes growing from the sediment and the water flow in the basin makes it difficult for macrophytes to grow as they prefer stagnant water', extreme interventions will be needed to permit a good working of the constructed wetlands. The proposition of implementing float lands on the basin(see figure 18), can be an alternative solution to the problem of depth. (Evie Cox, 2016).

In case of grey wastewater, different experiments have been conducted to determine the amount of space needed to purify water for one person. According to Sakkas (2013), a VSSF of 3 m² and 100 cm deep is enough to treat black water for one person. In case of grey water, 2 m² are enough (Sakkas, 2013).

Out different experiences, guidelines for the design and construction of a VSSF have been established in detail by Vymazal et al. (2001) and can be used as inspiration. Designed for a four persons single house, 'the system consists of a 2-m3 three-chamber sedimentation tank, a level-controlled pump, and a 15-m2 VSSF wetland. The main points of the guidelines are:

- The sewage must be pre-treated in a two- or three-chamber sedimentation tank (minimum size 2 m3 for a single household with up to 5 PE).
- The necessary surface area of the VSSF wetland is 3 m2 per PE (minimum size for a single household is 15 m2).
- The effective filter depth is 1.0 m. The filter medium is sand with a *d*10 between 0.25 mm and 1.2 mm, a *d*60 between 1 mm and 4 mm, and the uniformity coefficient (*U*=*d*60/*d*10) should be less than 3.5. The contents of clay and silt (particles less than 0.125 mm) must be less than 0.5 %.
- The filter bed must be enclosed by a tight membrane (minimum 0.5 mm thickness). The membrane must be protected by a geotextile on both sides.
- The bed is planted with common reed (*Phragmites australis*). The main function of the plants is to counteract clogging of the filter.
- The sewage is distributed evenly over the surface of the bed by a network of pressurized distribution pipes. The distribution pipes are insulated against frost by a 0.2-m layer of coarse wood chips or seashells on the surface of the filter.
- The loading frequency of the bed is typically 16 to 24 pulses per day when half of the effluent water is recycled within the system.
- The treated water is collected in an aerated system of drainage pipes placed in a 0.2-m layer of coarse gravel in the bottom of the filter.
- Half of the effluent water from the filter is recycled to the first chamber of the sedimentation tank or to the pumping well to enhance denitrification and to stabilize the treatment performance of the system'(Vymazal et al., 2006).

Of course, the different constructed wetland systems will be combined and interconnected in hybrids systems according to the need. Every combination of the system has its advantages and its disadvantages. Thus a VSSF helophyte filter followed by an H-SSF helophyte filter has the more efficient at removing nitrogen from the wastewater while the reverse combination (HSSF - VSSF) more effective is in the removal of suspended solids. FWS helophyte filters and WSP's (waste stabilization ponds) can also be combined with the other three systems (VSSF, HSSF, and Hybrids), but due to the amount of required space, it's not often built despite their efficiencies (Nanninga, 2011).

The implantation of de CW systems on Marineterrein should also take into account the Dutch legislation of 1998 regarding of the design of a V-SSF helophyte system. The Dutch guidelines specify the amount 'of surface areas needed per p.e., the depth of the helophyte filter, the dimensions of the distribution and drainage pipes, pumping regimes, the construction materials used, operation and maintenance

requirements and pre- and post-treatment options.' Note that the V-SSF helophyte filter is the only certified system to treat domestic wastewater and its efficiency for certain pollutants (such BOD, COD, N, P or TSS) have been tested and quantified by KIWA 2000 in order to obtain an IBA label if the VSSF fulfil the requirements (see table 3 & 4) (Nanninga, 2011). The Dutch guidelines are very detailed in the way the VSSF should be implemented (the diameter of the pipes, the distance between perforations, the recommended types of plants (*Phragmites australis* known as common reed, *Zantedeschia aethiopica, Canna flaccida, Lemnaoideae* known as duckweed, *Arundo donax* known as giant reed, *Typha latifolia* like reed mace, cattail or bull rush, or *Symphytum officipale* known as common Comfrey) the number of plants per square meter, their maintenance, or simply the fitting constructed wetland systems each plants (Nanninga, 2011).
To fight against turbidity which can be caused by toxic phytoplankton blooms, a coverage of 25-50% of water should be reserved for floating and submerged vascular plants. 'The 25% macrophyte coverage determined to cause a low phytoplankton concentration and the 50% coverage was determined enough for biomanipulation (Evie Cox, 2016).
'The dimensions of a helophyte filter, as well as the amount of wastewater that is applied on the helophyte filter, determine the Hydraulic Retention Time (HRT). This, in turn, determines how much time the different processes have in order to take place to remove pollutants'(Nanninga, 2011). The HRT is of course influenced by the state of medium (in the case of SSF systems) which can sometimes cause clogging.
Concerning the implementation on a building facade, the constructed wetroof (CWR) system is a perfect example of how to implement wetland principles on a building. 'A major limitation when constructing a natural wastewater treatment system on a roof is the load bearing capacity (LBC), the maximum weight a structure can resist' (Zapater Pereyra, 2015). The CWR system responds very well to all those issues and at the same time ensuring an effective treatment of wastewater (see figure 19).

6. Construction and maintenance costs

Using constructed wetlands to clean sewage wastewater is not more expensive than the conventional sewage system. Nevertheless, extra costs (operation and maintenance costs, sometimes renewal costs) can occur besides the construction costs, which explains well why the conventional system is preferred (Nanninga, 2011). Between systems themselves, the difference in term of costs seems to occur. So an HSSF system is more expensive than an FWS system even if the maintenance costs remain low compared to other alternative systems. 'HSSF wetlands have been utilized for smaller flow rates than FWS wetlands, because of cost and space considerations. HSSF wetlands are typically comprised of inlet piping, a clay or synthetic liner, filter media, emergent vegetation, berms, and outlet piping with water level control'(Kadlec and Wallace, 2009).
The degree of purifying wastewater has also an impact on the costs of a constructed wetland. For wastewater Nanninga (2011), with his 'low-quality-demanding-use costs' concept, suggests to skip some treatment steps in order to ensure a minimal water quality which can be recirculated in the water chain (Nanninga, 2011).
Depending on the location morphology mechanical means such a pump may be needed to ensure a good working of the CW system. In that case aspects such 'as energy, operational and maintenance skills, availability of spare parts, the technology to regulate the pumping and notify the operator of errors to become critical for the functioning of the entire wastewater treatment system'(Nanninga, 2011).

7. Conclusions

Constructed wetlands are an effective and ecological way of clean wastewater. FWS helophyte filters systems have shown their great efficiency at removing suspended solids, Phosphorus(P) from wastewater, but seem to be land-intensive systems. HSSF systems are even more effective than the FWS systems but ask twice more space for the same amount of treated water (by FWS and VSSF both). Of course, this effectiveness of HSSF systems is due to its higher hydraulic conductivity causing move surface bound reactions with plants. VSSF systems are even more efficient at removing pollutant than the HSSF systems because of the high exposition of the wastewater to oxygen which encourages the microbial biomat formation (see figure 20). 'VSSF helophyte filters allow for nitrification and Biological Oxygen Demand (BOD) removal but have poor suspended solids-removal, whereas HSSF have good BOD and suspended solids-removal but poor nitrification rates'(Nanninga, 2011). Hybrid systems are even more effective because they can be combined in such way that the qualities of every system can be used. Of course, they are expensive and difficult to implement but their performance is without equal.

The case of Marineterrein, specific plants has to be implemented in order to target specific pollutants. In their master thesis 'In Touch With Urban Water'(2016), two species of plants (*Ceratophyllum demersum* known as rigid hornworts and known, *Nuphar lutea* as yellow waterlily) have been chosen for their ability to clean water and tested on the site (Evie Cox, 2016). Macrophytes plants have also the ability to increase the biodiversity by 'reducing turbidity, introducing oxygen and at the same time purifying from nutrients, bacteria and heavy metals'(Evie Cox, 2016).

As an answer to the main question of this research paper on how to implement phytoremediation on and around a new building in order to make canal water suitable for swimming, two answers emerged from this research:

- The use of Hybrid CW system to purify the basin water and make suitable for swimming. This means targetting the existing pollutants (include *E. coli* and intestinal Enterococci, or Cyanobacteria which cause turbidity) using specific macrophytes plants or organism (*Ceratophyllum demersum).*
- The use Constructed Wetroof (CWR) system as inspiration on how to implement a constructed wetland system on a building. Issues such as weight or clogging have been taken into account.

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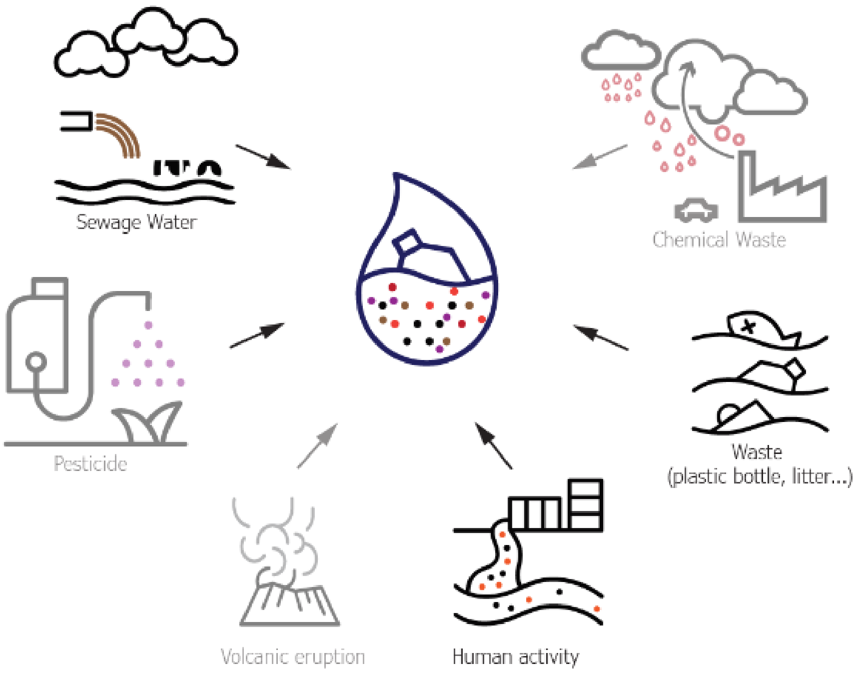
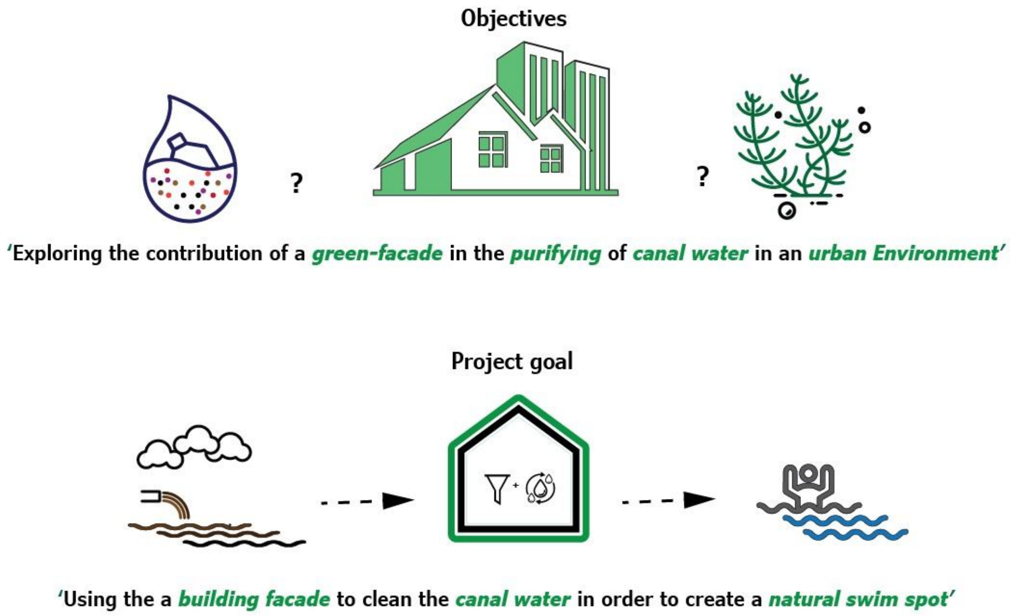
9. Appendix
9.1. Figures



(Ndayizeye, 2017)
Figure 1. Origin of the different type of pollutants in an urban area according to E. Pilon-Smits (2005)

(www.zwemwater.nl)
Figure 2. Lack of natural swimming spots in the city center of Amsterdam



(Ndayizeye, 2017)
Figure 3. A new active façade-system has to be developed in order to remediate Marineterrein water and make it suitable for swimming

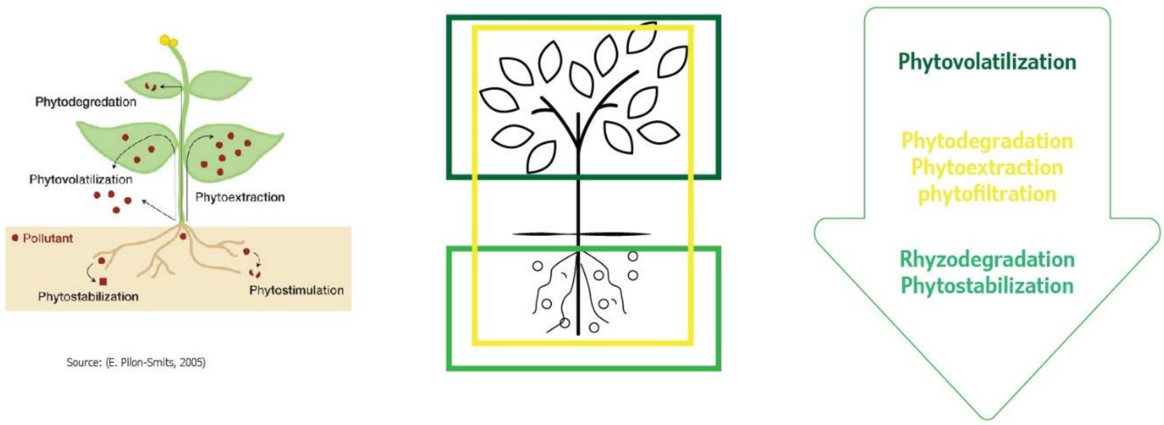
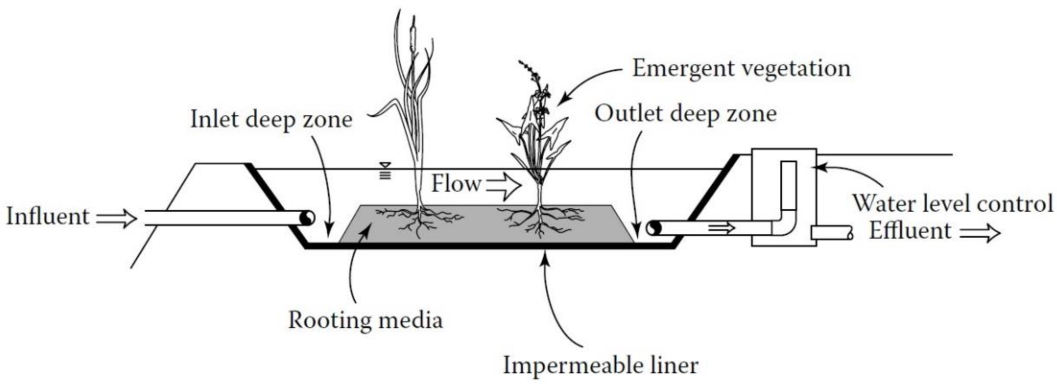
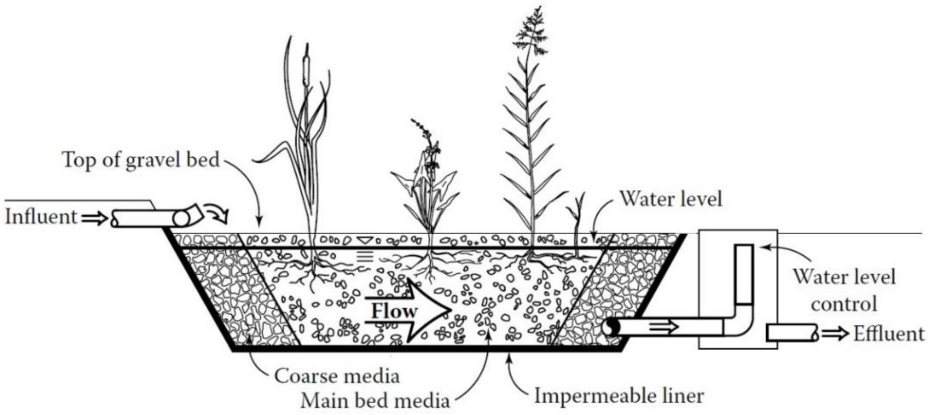


Figure 4. Phytoremediation principles

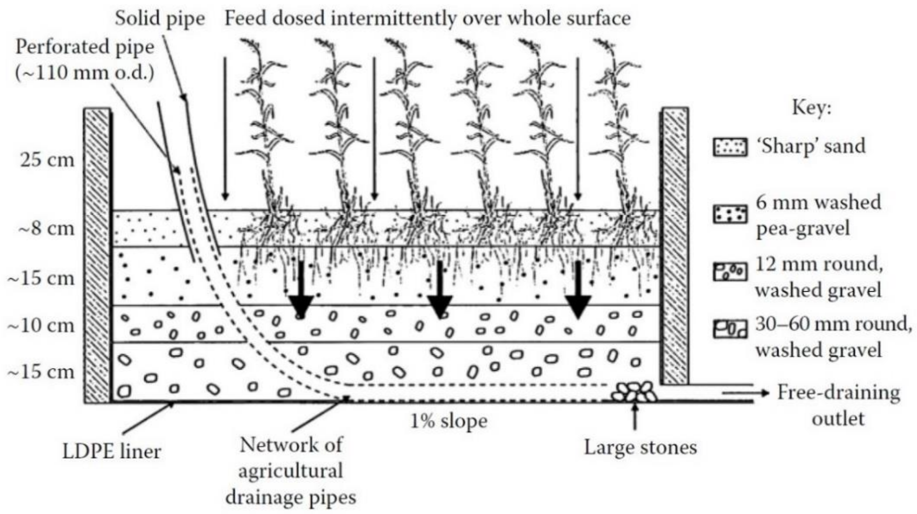


(Kadlec and Wallace, 2009)
Figure 5. Free water surface (FWS) wetlands principle

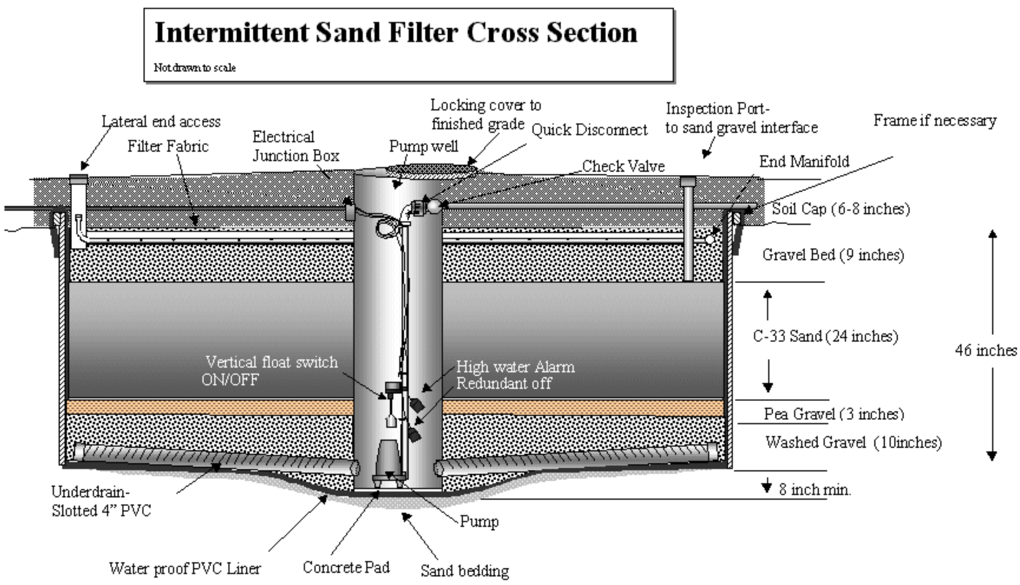


(Kadlec and Wallace, 2009)

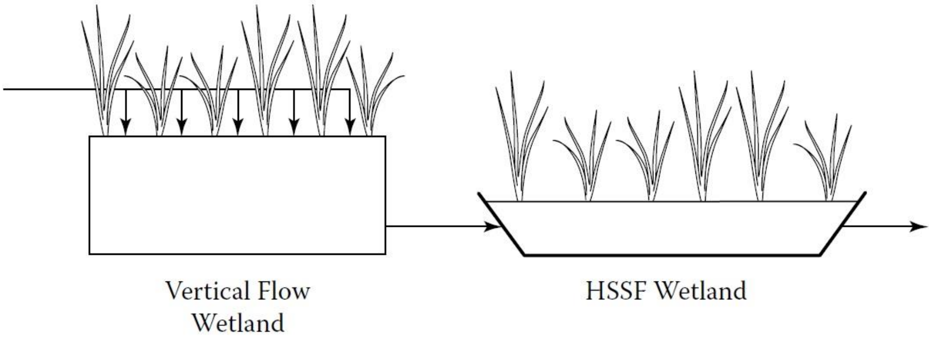
Figure 6. Horizontal subsurface flow (HSSF) wetlands



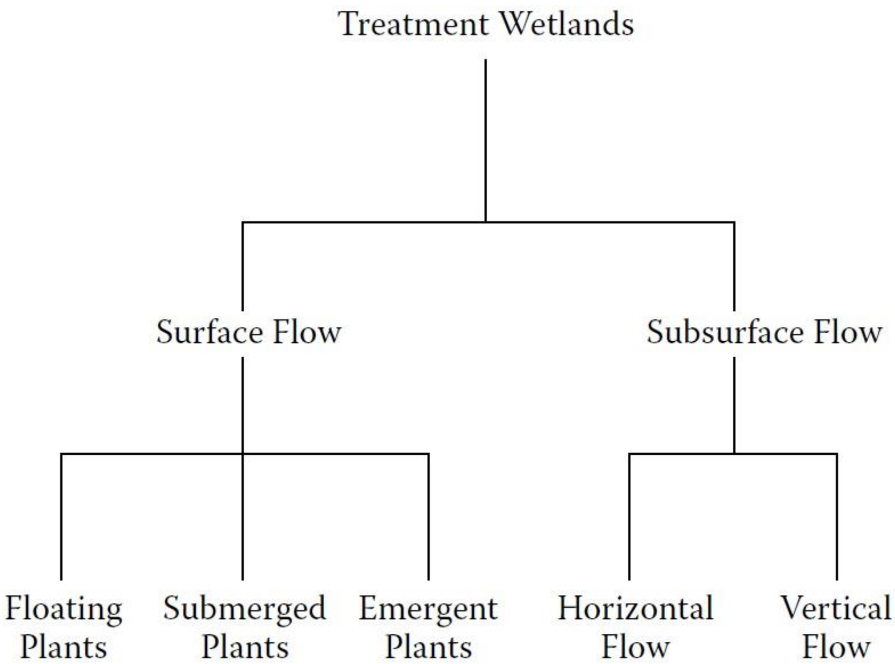
(Kadlec and Wallace, 2009)
Figure 7. Vertical flow (VF) wetlands



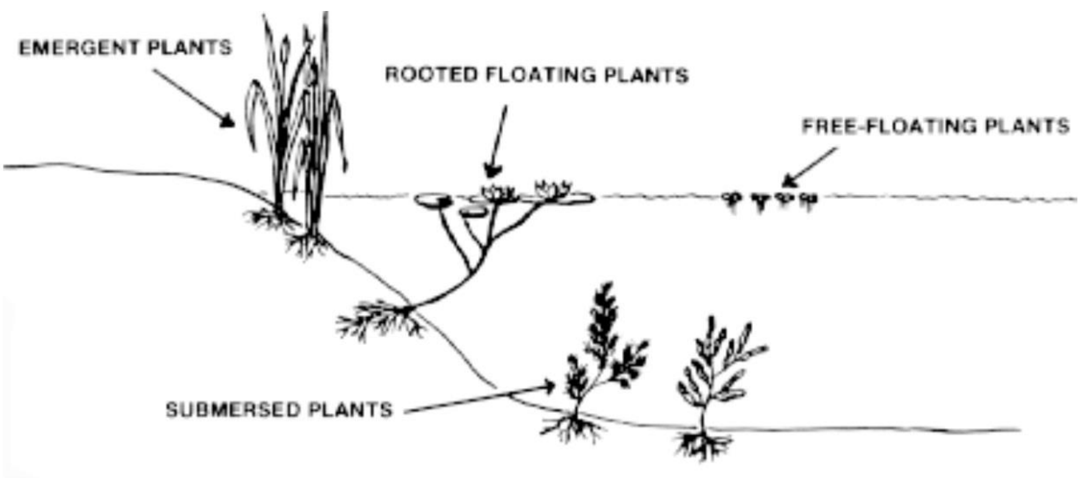
(www.septicplus.com)(Septic Plus)
Figure 8. Intermittent Sand Filter system



(Kadlec and Wallace, 2009)
Figure 9. Hybrid constructed Wetlands

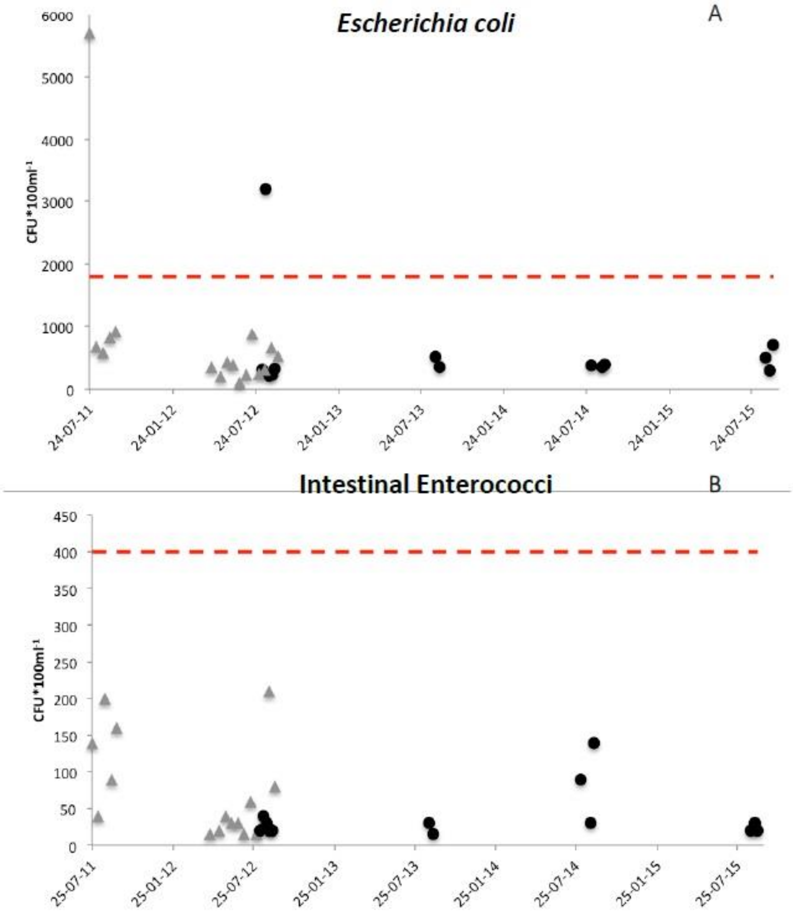


(Kadlec and Wallace, 2009)
Figure 10. Treatment Wetlands Options



(Evie Cox, 2016)
Figure 11. Aquatic vascular plants in different growth forms: Emergent plants, Rooted floating plants, submersed plants and free-floating plants

(Marineterrein.nl)
Figure 12. Collecting samples every 2 weeks for testing pollutants



(Marineterrein.nl)
Figure 13. Measurements of concentrations of E. coli and intestinal Enterococci on location from 2011 until 2015 (black dots) and (grey triangles) with the warning threshold (red dotes line). Bacterial concentrations as Culturing Forming Units (CFU) per 100ml

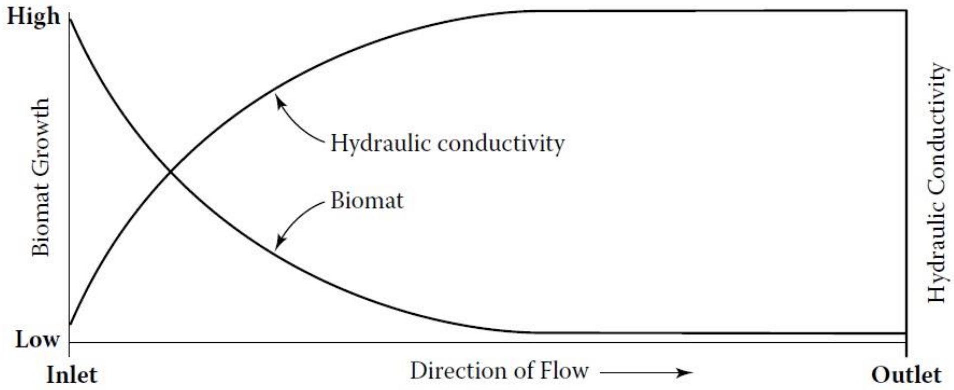


Figure 14. Biomat growth vs Hydraulic Conductivity

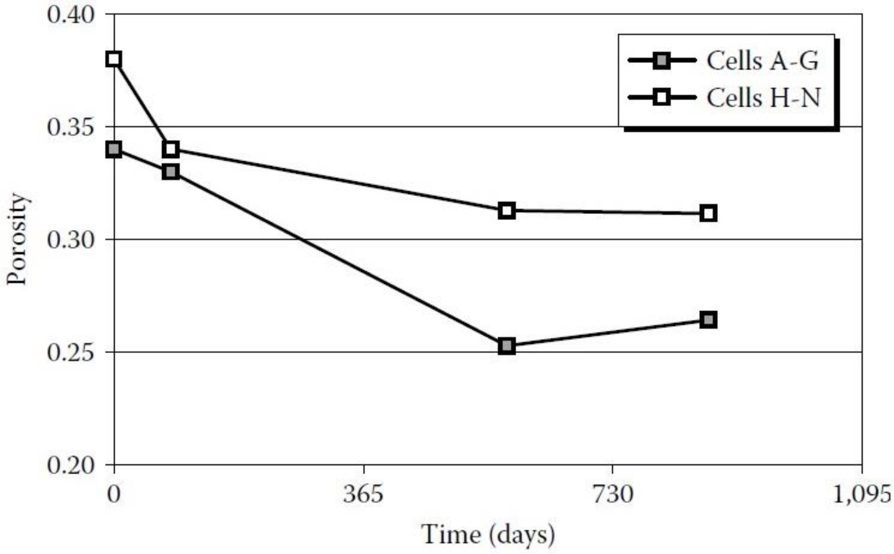
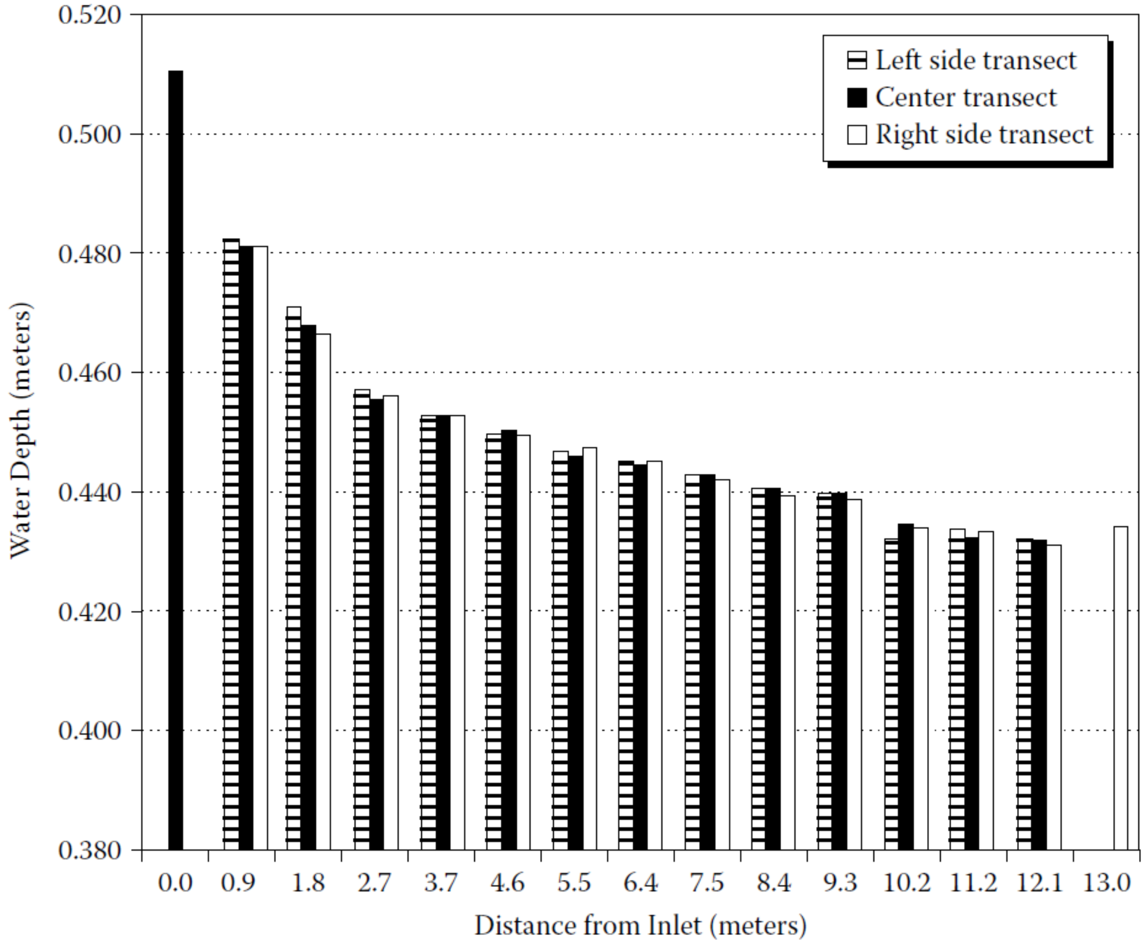
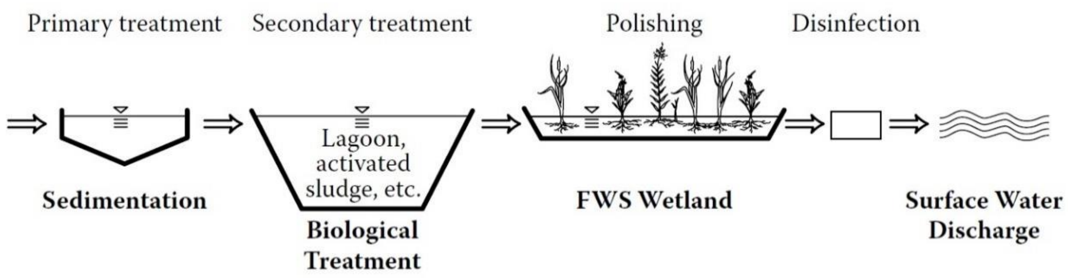


Figure 15. Porosity through the Time (days) of a clean bed



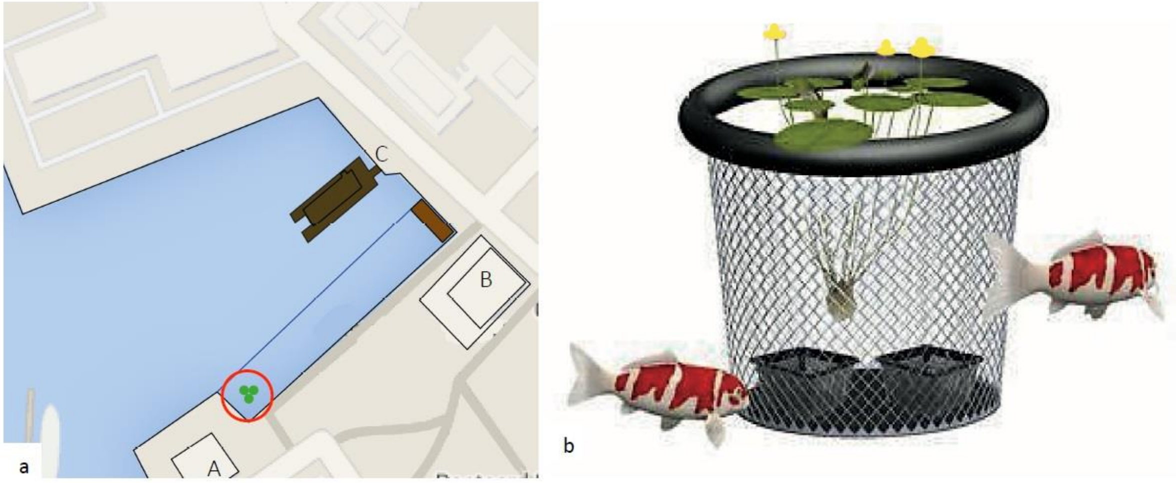
(Kadlec and Wallace, 2009)

Figure 16. Water surface profile of a single-home HSSF wetland in Alabama

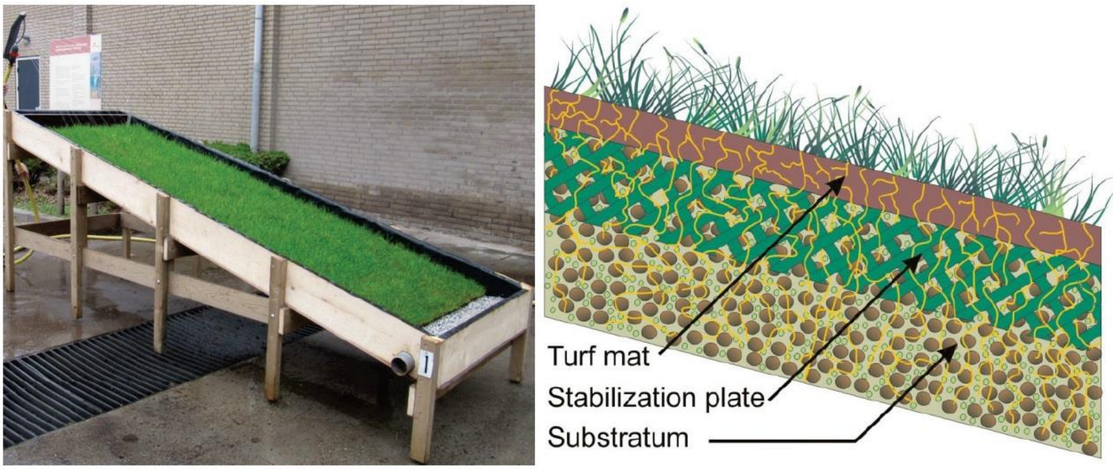


(Kadlec and Wallace, 2009)

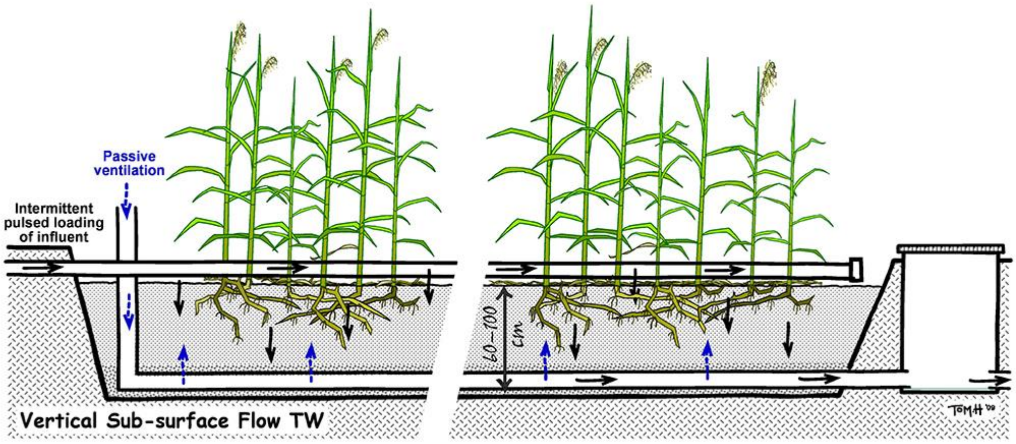
Figure 17. FWS wetland application



(Evie Cox, 2016)
Figure 18. The map of the open day (a)(3 July 2016) with Bureau Marineterrein (A), Pension Homeland (B) and the pier of the Royal Dutch Navy (C). In the basin the ponton (brown) from the Scheepsvaartmuseum, with a buoy line. The green circles are the three submerged gardens (red circle). This location is their definite place. Three submerged gardens (b) are introduced in the basin of Marineterrein. This garden exists of a basket with a floating ring (ø 100 cm, depth 80 cm). The baskets are anchored to the sediment in the basin by a brick.



(Zapater Pereyra, 2015)
Figure 19. Testing-table (left) and the constructed wetroof selected matrix (right)



(Group, Unknow)
Figure 20. Transfer of oxygen in a V-SSF system

9.2. Tables

Table 1. Norms for different quality catergories for natural surface water for intestinal Enterrococci and Escherichia coli

Parameter	Excellent quality	Good quality	Acceptable quality	Warning threshold (***)	Reference-methods for analyses
Intestinale enterococci (kve/100 ml)	200 (*)	400 (*)	330 (**)	400	ISO 7899-1 or ISO 7899-2
Escherichia coli (kve/100 ml)	500 (*)	1000 (*)	900 (**)	1800	ISO 9308-3 or ISO 9308-1

(*) Based on rating on the 95-percentile of the probability distribution. See *Zwemwaterrichtlijn* Appendix II[29].
(**) Based on rating on the 90-percentile of the probability distribution. See *Zwemwaterrichtlijn* Appendix II[29].
(***) When warning threshold is exceeded, a negative swim advise (at official swim spots) is given by Waternet.

(Marineterrein.nl)

Table 2. Sampling strategy and data interpretation

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

(Nanninga, 2011)

Table 3. Influent concentrations that a VSSF helophyte filter should treat as prescribed by KIWA (2000) (wastewater production is assumed to be 150 l/c/d)

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

(Nanninga, 2011)

Table 4. Pollution concentrations in effluent of an IBA Class IIIB wastewater treatment technology, in any 24 hr. composite (KIWA, 2000)

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

(Nanninga, 2011)

Table 5. Examples of applications and efficiency of wetlands for quality improvement of water

Type of pollutant	Efficiency (% removal)	References
Macronutrients		
Ammonium-N	16-67	12, 14
Nitrate/nitrite	40	13
Total Kjeldahl nitrogen (TKN)	49-81	14, 20
Organic nitrogen	82	14
Soluble Reactive Phosphate (SRP)	56	13
Total-P (TP)	44-68	12, 13
Metals and metalloids		
Al	81-97	17
As	65	15
Ba	70-95	17
Cd	58-71	17
Co	39-98	16
Cu	49-65	17, 18
Fe	91-97	16, 17
Mn	91-99	16, 17
Ni	22-67	16, 17, 18
Se	69	22
Sr	24-51	17
Zn	52-95	15, 17, 18
V	100	17
Organic compounds, including explosives	63-100	19, 20, 21
Coliform bacteria	26-98	18
Eggs of human parasites	94-100	23
COD	81	20
BOD_5	72-89	12, 14, 20
Suspended solids (SS)	43-94	12, 14

(Mackova et al., 2006)