Blue Green Dream

Deltares

Constructed Wetlands redefined as Functional Wetlands

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Titel
Constructed Wetlands redefined as Functional Wetlands

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Samenvatting
Constructed wetlands (or “helophyte filters” in Dutch) are man-made wetlands, which exploit the processes that occur in ‘natural’ wetlands in such a way that the primary objective is to purify water. Constructed wetlands are used all over the world for this purpose. Over the years, the number of types has increased and there has been great improvement in the clarification of the number of functions a constructed wetland could have. Within cities worldwide, many problems exist, such as risk of flooding, contaminated surface water and the heat-island effect. As an alternative for hard-engineering measurers, eco-engineering measures (such as constructed wetlands) could be used. Such measures are relatively cheap and they have the potential to combine multiple urban functions at the same time. Apart from water purification, constructed wetlands could be used in cities for (among others) recreation, nature, water retention, cooling and feeling of well-being for citizens. There are many possibilities for innovation and improved implementation in urban areas: constructed wetlands could be more successfully implemented in and near cities when different interests and functions are combined within one wetland and when the water purification function is expanded.

Referenties
-Fonder N & Headley T. 2010. Systematic classification, nomenclature, and reporting for constructed treatment wetlands. *Water and Nutrient Management in Natural and Constructed Wetlands* chapter 15, p 191 – 218
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Annex

1 Introduction

Everywhere in the world, constructed wetlands are being used for water purification. Over the years the number of types has increased. There has also been great improvement in the clarification of the number of functions a constructed wetland could have. There are many possibilities for innovation and improved implementation in urban areas. In this research 49 urban constructed wetlands in the Netherlands, U.S.A. and Australia were analyzed; their function, type and factors of success were included in the study. The main questions addressed in this report are: 1. What are constructed wetlands? 2. When and where are constructed wetlands successful? 3. How could they be more successfully implemented near and in cities?

2 Constructed Wetlands

Constructed wetlands (or “helophyte filters” in Dutch) are man-made wetlands, which exploit the processes that occur in ‘natural’ wetlands in such a way that the primary objective is to purify water. These wetlands contain helophytes, which are marsh plants of which the buds survive the winter below the water surface. Oxygen is transported to the anaerobic (water-saturated) soil via the roots of the helophytes. This creates an aerobic zone around the roots. In this aerobic zone, two important mechanisms take place: ammonification and nitrification. Eventually, nitrate and atmospheric nitrogen are formed. The atmospheric nitrogen is emitted as a gas into the atmosphere and nitrate is transformed to nitrous oxide in the anaerobic zone, via a process is called denitrification. Ammonium that is produced in the aerobic zone could be taken up by plants as a nutrient. Phosphorus is predominantly filtered/removed from the water through the binding to iron, aluminium and calcium ions. This could be achieved via a reversible process (adsorption) or a non-reversible process (precipitation). Furthermore, phosphorus could precipitate with sediment when it is bound to it. The most important processes for water purification in a constructed wetland take place in the soil.

The first constructed wetlands showed a high similarity to natural wetlands. A good example of such a constructed wetland is a wetland in the Flevopolder (the Netherlands), which was built in the end of the ’60. This is one of the first fully functioning constructed wetlands in the world. In this type of wetland, the water flows over a bed of helophytes, after which it sinks into the soil. This is a process that also occurs in natural wetlands. The main difference between the first constructed wetlands and natural wetlands was that the constructed wetlands were designed to achieve optimal utilization of the area, which often meant that long, parallel ditches were planted with helophytes (usually *Phragmites australis*).

Over the years, the concept of constructed wetlands has gone through a major technological development, and many new types arose which all work differently for water purification. The biogeochemical processes that occur in a natural wetland are optimized for water purification, predominantly for nutrient removal. Eventually, a range of different types developed; the most important types and their characteristics are shown in Figure 1 (based on Fonder & Headley, 2010).

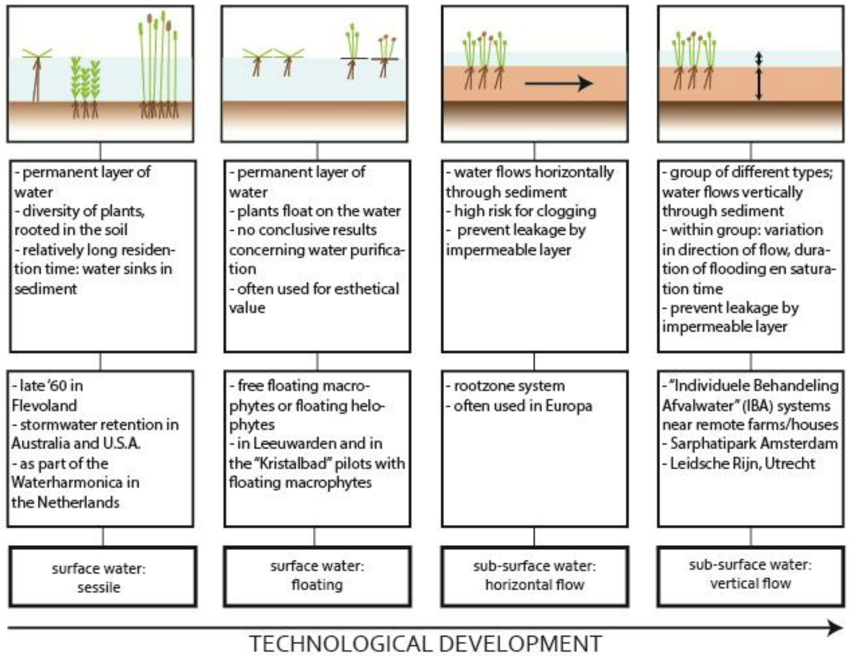

Figure 1: overview of different constructed wetland types and their characteristics. The different types are sorted according to technological development. (based on Fonder and Headley, 2010)

Constructed wetlands can be divided into two groups, those with surface water and those without surface water. In types without surface water (sub-surface water), the water is in more close contact with the sediment. Because of this, water purification works better. Vertical flow constructed wetlands are designed to create specific anaerobic and/or aerobic conditions, in order to enhance the nitrogen removal from the water. Different types of constructed wetlands can also be linked together to create a higher purifying capacity.

Often, the term "helophyte filter" is correlated with types of constructed wetlands with surface water, in which plants play a central role. Due this limited view, other types of constructed wetlands can be missed and this possibly results in a constricted view on the term "helophyte filter". It implies that helophytes play a crucial role in purification and that purifying (i.e. filtering) is the most important or only function of such a wetland. However this is not the case, the most important processes occur in the soil. Helophytes do help with creating suitable circumstances for water purification. In addition to that, constructed wetlands can have additional functions. The term "helophyte filter" addresses this insufficiently. Even the term "constructed wetland" is insufficient because it misses the fact that a wetland could have different functions. This is also the case for the term "helophyte filters". The term "constructed wetlands" just says that the wetland is constructed by humans, and it says nothing about its functions.

Since the '60, constructed wetlands are widely used in the Netherlands and in the rest of the world. In Europe, usually systems with sub-surface flow are chosen, while in the U.S.A. and Australia systems with surface flow are very popular. The reason the U.S.A and Australia often use surface flow systems is due to the fact that in these areas water purification (with relatively low concentrations of nutrients in the effluent) is often combined with water retention. In the U.S.A. and Australia, there is a lot of land available, which makes it easier to install constructed wetlands with large surface areas. Large surface areas are beneficial to the retention capacity and will allow, even in wetlands with surface water, high nutrient removal efficiencies (e.g. via the precipitation of sediment-bound phosphorus).

Due to the high retention capacities and better circumstances for nutrient removal, constructed wetlands are often seen as a successful measure in the U.S.A and Australia.

3 Functions and benefits of constructed wetlands in cities

Within cities worldwide, problems such as risk of flooding, contaminated surface water and the heat-island effect exist. There are several solutions for these problems. As an alternative for hard-engineering measurers, eco-engineering measures could be used. Such measures are relatively cheap and they have the potential of combining multiple urban functions in one measure. Constructed wetlands are a good example of such an eco-engineering measure and they could help solving the above mentioned problems that could occur in cities.

Apart from water purification, constructed wetlands could be used in cities for (among others) recreation, nature, water retention, cooling and feeling of well-being for citizens. An overview of different functions and benefits of constructed wetlands is given in Table 1. The table is based on the basic concept of a constructed wetland, such as shown in Figure 2. The basic concept consists of a collection of elements. Important elements of the basic concept are the permeable layer of soil (the most important purifying processes take place in this layer), the water column (although not present in every type), the plants (biomass) and added substances such as metals to enhance phosphorus removal. Together with other factors such as the retention time of the water and surface area, these elements form the parameters that can be tweaked to change the basic concept. However, the capacity to purify water should never be lost. For each function the most important parameters are listed in the third column of Table 1.

There are many parameters that can be changed for water purification. Parameters depend strongly on the type of wetland: surface flow and sub-surface flow wetlands differ greatly in their designs. Therefore, surface and sub-surface flow wetlands are listed in different rows in the table.

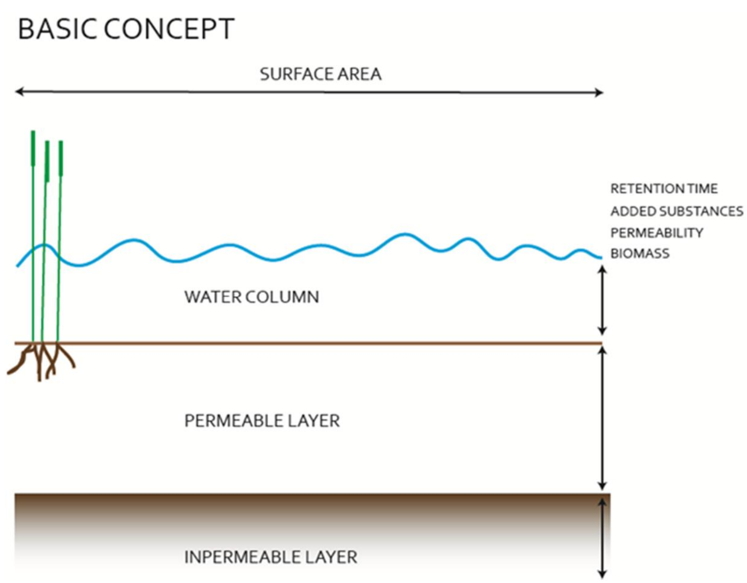

Figure 2: basic concept of a constructed wetland + most important parameters

Table 1: Overview of functions and benefits. Functions that can be optimized similarly are on the same row. In the second column, the contribution of a constructed wetland to different functions is listed. In the third column, the most important parameters for each function are listed.

Functions and benefits	Performance	Important parameters
Water purification (sub-surface water)	+	Dimensions wetland, added substances, biomass, residence time, permeability, distribution water in wetland
Water purification (surface water)	+/-	Surface area, added substances, biomass, residence time, permeability
More O_2 in the air Air purification Reduce noise pollution	+/-	Biomass (trees, shrubs)
Counteract urban heat island effect	+	Biomass Specific Leaf Area (evapotranspiration)
Green areas in the city Feeling of well-being citizens	+	Biomass
Education	+	No specific parameters
Recreation	+/-	Extra features such as benches or walker paths
Ecological value Food production	+	Surface area, different (plant) species, Height water column
Discharge of water	-	Biomass Permeability Outflow velocity
Water retention	+	Dimensions wetland
Energy production from biomass	+/-	Biomass (if right species)

4 Optimization on different functions

Constructed wetlands can potentially be optimized for most of the functions. The wetlands could have a positive effect on the ecological value in a city: wetlands with surface water (that resemble natural wetlands) contain a permanent layer of water and compared to sub-surface flow wetlands the landscape has a higher heterogeneity. Because of this, different types of plants (emergent, floating or submerged) could occur in the wetland and fish could live in the water layer. The plants are of crucial importance to the ecological value, because the plants could provide habitat and food for all kinds of organisms. This could be in the form of trees, nectar producing plants, hedges of plants that carry fruits or berries. Wetlands with sub-surface water could also add to the ecological value, but to a lesser extent than wetlands with surface water. It is possible to plant different helophyte species to create a diverse wetland. However, when reed is planted, the system is likely to go towards a mono-culture (with only reed) because reed is very intolerant to other species.

Constructed wetlands cannot be optimized for every function or benefit. The effect of O_2 production, air purification and noise reduction on the environment is relatively small (see Table 1); there are many plants needed before a significant effect is achieved. Therefore, a “+/-“ is listed in the table for these functions. The type of plant and how the plants are placed are also important. To counteract noise reduction, high and dense vegetation is needed. This could be achieved by placing broad-leaved trees or a dense shrubbery. Trees could also help to purify the air. Evergreen trees with a specific leaf area are (potentially) the best option to counteract air pollution. When trees are placed in clusters close to the source of pollution, the effect could be bigger. Examples of suitable trees are *Alnus glutinosa*, *Fraxinus excelsior* and *Ulmus minor*. *Ribes nigrum, Prunus padus* and *Viburnum opulus* are examples of suitable shrubs.
Also for biomass production, constructed wetlands do not function optimally. Experiments show that it is possible to produce energy from helophytes. Reed, for example, is a commonly used species in constructed wetlands and it could be very well used for biomass production (it has a high yield compared to a low input). However, in practice, there are not many successful cases. The removal of reed and other harvestable biomass is expensive, which could be a reason to abandon the idea to use biomass as an energy source in constructed wetlands. In the Netherlands, at the sewage treatment plant in Land van Cuijk, there was an attempt to use Duckweed for biomass production. However, this attempt was unsuccessful because it turned out be very hard to excavate the Duckweed from the water and the Duckweed had to stay on the banks for 2 days before it could be processed because of the Dutch Flora and Fauna law.

Constructed wetlands are seldom used for a fast discharge of water. A certain retention time is needed for optimal water purification and this might have a counteracting effect on the flow of water through the wetland. However, technically it is possible to optimize a constructed wetland on water discharge, especially when the water purifying function is (temporarily) abandoned. Whether a constructed wetland can be optimized on (fast) discharge of water depends on the objective of the project.

5 Dutch examples

Results concerning the water purifying function of constructed wetlands are often precarious or they lack completely, especially in the Netherlands. Because of this, there might be mixed feelings about the functioning of constructed wetlands. In the Netherlands, many wetlands with surface flow have been installed. They show different results concerning their abilities to purify water. A well-known example is a constructed wetland at Stad van de Zon in Heerhugowaard. After monitoring, it turned out that the effluent did not contain significantly lower concentrations of target substances. Another example is the before mentioned constructed wetland at Land van Cuijk. This wetland never worked well: it got saturated with phosphate and to achieve sufficient nitrate reduction a sand filter was needed. The wetland could not meet the high expectations. There are surface flow wetlands in the Netherlands that do work well: in Houten three constructed wetlands have been installed which meet the expectations and also in Soest lays a wetland that functions very well. In both cities, water purifying efficiencies of 90% or higher are achieved. Another, very well-studied example is the wetland of Everstekoog on Texel. The wetland was placed to filter effluent from a sewage treatment plant and it was able to remove an additional 25% of target substances from the effluent. An important result (which formed the basis of the Waterharmonica-concept) was that the composition of suspended solids changed from sludge to aquatic plankton.

The more-advanced systems without surface water show (provided that they are well managed) reasonably consistent results. A good example of such a well-working system is the application of IBA-systems in the Flevopolder in the Netherlands. These IBA-systems are placed near houses and farms that are not connected to the sewage system and can achieve removal efficiencies of at least 90%.

6 The combination of multiple functions in one wetland

A constructed wetland which combines several functions could address multiple problems at once. A good example of such a wetland in the Netherlands is a constructed wetland near Hoogeveen. In this wetland, water purification is successfully combined with water retention, ecological value and recreation. Different stakeholders with different interests were involved: the sewer system of the city had to be improved, the area north of Hoogeveen was appointed as urban fringe zone, the ecological connection zone lays near the city and upstream water retention was needed to prevent water surpluses from reaching the city of Meppel. The constructed wetland of ca. 6 hectares is the result of an integrative approach where all different interests have been taken into account.
There are also examples of constructed wetlands abroad where functions and interests are combined, for instance in the U.S.A. or Australia. Often, water purification is combined with water retention and ecological value. In Australia, the community is to a great extent involved in the design and management: there is for example education/recreation for children and adults.

To address the effect of optimization of one function on other functions, scenario-analysis was performed. Not all functions can be combined easily, because optimization on one function could have a negative effect on another (often on water purification). Optimization on recreation and water discharge might pose a risk: extensive recreation could cause disturbances, which could have a negative effect on for instance water purification or ecological value. In some cases, recreation near or in the wetland could pose a risk to human health: if sewage treatment effluent is involved, certain measures might be required to prevent contact with recreational users. For water discharge, fast removal of water is usually required. For most of the functions, optimization means either an increase of biomass in the wetland or an increase of wetland volume. This is disadvantageous for the discharge of the water (or hydraulic capacity) because the residence time of the water needs to be increased. Further research is needed to investigate the precise effects of optimization of one function on other functions.

Combining multiple functions in one wetland is not a determining factor for success. Wetlands where no functions are combined could still be successful. An overview of functions is made for several cases in the Netherlands, U.S.A. and Australia. This is shown in Table 2. Per area, successful and non-successful cases are indicated.

7 Networks of wetlands

A chain of constructed wetlands in a network has a positive effect on functionality. The water purifying efficiency increases for instance when multiple wetlands of different types are connected. This has primarily been done with sub-surface flow constructed wetlands. A network of constructed wetlands also has a positive effect on the ecological value. Scientific studies show that organisms migrate through a city via green areas or “stepping-stones”, also named corridors. These corridors do not just link green, rural areas, but serve as a habitat for flora and fauna as well. Constructed wetlands can be used (if placed at the right spot) as stepping stones for biodiversity.

Apart from ecological value and water purification, networks of constructed wetlands could also enhance the reduction of noise pollution and they could help to counteract the urban heat island effect. Vegetation helps with cooling by evaporating water. Furthermore, vegetation creates an open structure in the city which moves the air and causes the city to cool.

Another way of forming a network is to construct a network with different measures (instead of different wetlands). A good example of such a network is the Waterharmonica in the Netherlands. Apart from constructed wetlands, other measures like sand filters are used in this chain to help making the water more “alive” after it has been cleaned by a sewage treatment plant: a buffer is created between the effluents from the sewage treatment plants and the surface waters to which it is discharged. In the U.S.A. constructed wetlands are often combined with other measures such as bioswales and green roofs. Of the 21 successful cases in the U.S.A. (23 in total, see table 2), in 12 cases constructed wetlands are combined with other measures.

8 Purifying processes

Pollution is a world-wide problem in cities: cities are polluted with heavy metals, nutrients, pathogens, PAH's, pesticides, and other pollutants. Water purification focused, up until now, primarily on nutrient removal. This is reflected in the different types of constructed wetlands, which differ in their anaerobic and/or aerobic conditions. When constructed wetlands could be optimized in such a way that they could filter more kinds of pollutants in cities, they could contribute to a healthier environment. This could be achieved by the optimization of constructed wetlands on purifying processes that are needed to filter these substances from the water, such as sorption, biological pest control or photodegradation. Fluctuating water levels could contribute to nutrient removal (N and P) and the removal of several metals.

9 Factors for success

Apart from the theoretical background, experience also affects the implementation of constructed wetlands in urban areas. Factors that were determining success were extracted from a dozen interviews with waterboards and municipalities. The biggest successes in the Netherlands were achieved when multiple interests were taken into account. In this respect, having a wide view is of crucial importance. The interviews showed that it is important to think carefully about management when designing a constructed wetland and to incorporate this in the budget. In many cases, no one looked after the constructed wetland after construction was finished and no money was budgeted for maintenance and monitoring. Because of this, in many cases it is unclear if the wetlands (still) work or whether they ever did at all. Maintenance of constructed wetlands is cheaper than it is for hard-engineering solutions. However, usually a very specialized form of maintenance is needed and this proves to be difficult to realize. Possibly, there is also a cultural aspect: for hard-engineering solutions, maintenance is standard and generally accepted, while for eco-engineering solutions maintenance is seen as an extra task.

Despite the fact that eco-engineering solutions are relatively cheap, often hard-engineering solutions are chosen. A reason for this is that for these systems there is a higher probability that they actually work and management practices are less specialized than for eco-engineering solutions. Furthermore, these systems don't take up much space, which is a huge advantage because less ground needs to be bought. Land acquisition is a crucial factor and has a big influence on the choice for a system.

Lastly, public access to the wetland and awareness are important factors for implementation. Free access for citizens could be a big disturbance and cause damage to the wetland. However, education could be a method to counteract these disturbances because it raises public awareness of the function(s) of the wetland. Good examples are found in Australia and the U.S.A. Especially in Australia, citizens are strongly involved in environmental issues. Apart from education for residents and schools, residents are involved in construction and maintenance. Public awareness and access to the wetland do not seem to be crucial factors for success: it seems that involvement of local stakeholders could help to prevent failure; wetlands where stakeholders are less involved could still be successful (see also Table 2).

Table 2: *Differences between constructed wetlands in the Netherlands, U.S.A. and Australia. Per area, wetlands are divided in two groups: successful wetlands and non-successful wetlands. Wetlands were defined as successful when the owner of the wetland had the opinion that it was successful. Within each group, wetlands were sorted according to type, size, whether or not they were placed in a network, combinations with other functions and to the degree of involvement of local citizens.*

Determinating factors for success	The Netherlands (12)		U.S.A. (23)		Australia (14)	
Success	**Yes**	**No**	**Yes**	**No**	**Yes**	**No***
Type	Surface water: 7 Sub-surface water: 1	Surface water:1 Sub-surface water:3	Surface water:21	Surface water:2	Surface water:10	Surface water:4
Size	Average: 1-5 hectares. Exceptions: 6 ha (surface water), <0,5 ha (IBA-systems)	Average: 0,5 ha Wetland with sub-surface water = 4 ha	Between 0,5 and 28 ha	<0,5 ha & 6,5 ha	Between 0,125 ha and 17 ha	No results:10 ha 2 are between 0,1 ha and 1 ha** 1: no surface area known
Network *Different measures* *No network* *Different wetlands*	 2 6 0	 1 3 0	 12 9 1	 2 0 0	 0 10 0	 0 4 0
Combination with other functions	Recreation: 3 Education: 0 Ecological value: 7 Green areas: 5 Waterharmonica (near sewage treatmen plant): 2 Retention: 7 No combinations with other functions: 1	Recreation: 1 (but secundair) Retention: 0 Education: 0 Ecological value: Green areas: 0 Waterharmonica (near sewage treatment plant): 1 No combinations with other functions: 2	Recreation: 9 Education: 10 Ecological value: 7 Public benefits: 8 Restoring degraded land: 2 Retention: 21	Recreation:0 Education: 1 Ecological value: 1 Public benefits: 0 Restoring degraded land: 0 Retention: 2	Recreation: 5 Education: 5 Ecological value: 6 Re-use water: 3 Retention: 3 No combinations with other functions: 2	Recreation: 1 Education: 1 Ecological value: 2 Re-use water: 2 Retention: 1 No combinations with other functions: 2
Involvement local citizens *High level of awareness* *Involved in process* *No/unknown*	 3 0 5	 0 0 4	 8 1 13	 0 0 2	 2 4 4	 0 2 2

**No = 3 are under construction. Of 1 case no results are known.
***Educated guess, based on map of the area

10 Conclusion

Constructed wetlands could be more successfully implemented in and near cities when different interests and functions are combined within one wetland and when the water purifying function is expanded. Successful optimization of several functions in one wetland addresses multiple problems at once and it could raise support among municipalities and citizens. Constructed wetlands cannot be optimized for every function or benefit. The functions recreation and discharge of water (see Table 1) are open for debate. Too much recreation in the wetland might lead to disturbance of the area, which could have a negative influence on water purification and ecological value. For water discharge, a fast flow of water is required. However, water purification usually requires a certain retention time of the water, so these functions may counteract each other. Support among citizens could be raised by education. Good education seems to help preventing failure; good examples for this are the Australian cases (see Table 2). Linking constructed wetlands in a network (of different wetlands and/or different measures) could improve their functionality. When constructed wetlands are optimized to filter more kinds of pollutants in cities, the wetlands could aid sufficiently to a healthier environment.

There is a world to win in the Netherlands concerning the implementation of constructed wetlands in urban environments, even though examples of successful cases are known. It is a world that might be won easier abroad, because in other countries such as the U.S.A. or Australia there is less skepticism about constructed wetlands. The application of (especially) surface flow constructed wetlands in the Netherlands has reached a dead end, mainly because of the mixed results for water purification and the bad reputation of these wetlands in the Netherlands. Other types of wetlands (with a higher potential for successful implementation) are missed and improvements in the field of policy-making are needed.

In the Netherlands, the name “helophyte filter” is not always perceived as meaning a wetland with a range of functions, which could hamper its application. Therefore, a new name is proposed: “functional wetland”. Apart from the fact that this name has no associations with surface water systems (which have a negative reputation in the Netherlands), the name fits with the idea that these systems could have more functions than just water purification.

11 Word of thanks

This research would not have been possible without all the people who were willing to help me during interviews: the people from Deltares, the Dutch waterboards and municipalities. They were very helpful and provided me with a lot of useful information for my research.

A special thanks to my supervisors Victor Beumer and Frans van de Ven, whose countless hours of discussions and meetings helped me with keeping a critical view on my research. The freedom that Victor gave me to make this research my very own encouraged me to make the most of it.

A thanks to my supervisor from Utrecht University, Jos Verhoeven, who supported me when I extended my internship and who was always enthusiastic about my project.

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A Appendix: case studies

Australia + USA (Green = Australian case studies):

Name	Specifications	Objective	Success	Maintenance	Comments
California Constructed Wetland: a cost-effective way for wastewater treatment	154 hectares of surface flow constructed wetlands near Arcata, California. Average Annual Flow: 8.706.447 liters/day Costs: +/- $5.000.000 for construction of wetland, annual maintenance costs: $500.000	Primary function: Water purification Secondary functions: -recreation -education -ecological value -feeling of well-being/green areas around city -restore degraded land	-the fact that it actually works to purify the water -combination of interests (see “functions and benefits”) -cheaper than “hard-engineering” option	Costs: $500.000 annually. Community is involved in maintenance.	http://www.ecotippingpoints.org/photo-gallery/usa-california-arcata-constructed-wetland-wastewater.html
Applebees Support Centre – Treatment Train, Lenexa , KS	Stormwater treatment wetland near restaurant support centre. 6.5 ha, combination with other measures (bioswales, rain gardens) in water treatment chain. Wetland = at the end of the chain. Costs: between $50.000 - $100.000	Restore ecological value, water purification, water retention	Average; wetland might be too small. Water purification not sufficient: large flow, minimal residence time. Waterbirds are serious problem. Sediment correction of upstream erosion problems and dredging the wetland would help improve its performance. Waterbuffer with deep water to discourage waterfowl to enter wetland might be another option for improvement.	Not considered in budget	
Sinclairs Restaurant Renovation, Lake	Stormwater treatment wetland combined with	Bioretention, water purification, public	Yes, positive reaction of citizens: area is well-	30 working hours annually	

Martin, AL	bioswale/bioretention facility. Wetland with native vegetation, 1-2 ha, costst: $10.000 - $ 50.000	education, enhancing property value	known, and it also served as model for water quality management techniques	
Railroad Park, Birmingham, AL	17.5 ha, brownfield → green space, wetland with native plants, costs $1.000.000 - $5.000.000	Education, stormwater filtration, recreation, provide habitat for wildlife	Nothing known about stormwater reduction performance, but recreation and education are a big success (catalyst for downtown sustainable living)	Wetland is designed to minimize maintenance
Rock Mill Park, Alpharetta, GA	Passive recreational park that serves as an educational exhibit for the City of Alpharetta, Integration of stormwater quality treatment facilities → bioretention cells, green roofs, enhanced swales, constructed wetlands +/- 1.5 ha, costs +/- $2.100.000, 2 wetland swales, model of low impact development	Education Ecological value Recreation Main goal of the project: protection and interpretation of natural environment while serving as a rest area for greenway path users	High pollutant removal rate, but that is for all measures together (80-100% removal). Project = model of cost-effective sustainable design	Nothing known
Interchange 25 Stormwater Treatment Wetland, Fulton County, OH	1.5 ha, costs $50.000 - $100.000	Designed to optimize the physical and biological processes of wetlands to uptake & filter sediment and pollutants in stormwater	25-75% reduction of particulates, nutrients and pollutants in stormwater. Enhanced economic development of surrounding community	40 hours annually

Reifsnyder Park Stormwater Treatment Wetland, Canton, OH	0.5 ha, at outfall of storm sewer discharge to a creek, urbanized area, costs $100.000 - $500.000	Elevated P-levels in the area, so objective is to filter P. Restore ecological value	Reduction of variety of pollutants of 25-75%	Nothing known
Mayfield Village Wetland Park, Mayfield Village, OH	+/-10 ha costs: $100.000 - $500.000	Water purification, stormwater retention	Reduced peak discharges of 25% Economic development adjacent office campus	Nothing known
San Joaquin Marsh and wildlife Sanctuary, Irvine, CA	Part of a network of 31 treatment wetlands; San Joaquin Marsh is the last step in the watershed for urban runoff before return to upper Newport bay/pacific ocean	Clean urban runoff, protect environmentally senstitive upper Newport bay, education, recreation, wildlife	70% N removal Education = success About the rest: no information	Nothing known
Steamer Landing Park and Shoeline Trail, Petaluma, CA	Combination of measures: stormwater treatment wetland, bioretention facility, bioswale, porous pavers, etc. costs: $500.000 - $1.000.000 for all measures together	Education/recreation/ managing stormwater runoff (retention)	80-100% of 2 year storm is retained + treated on site	35 hours of annual maintenance
Blackwell Urban Stream Research Center, Warrenville, IL	The Blackwell urban stream research centre facilitates re-introduction and augmentation of native freshwater mussels and fish species that were historically abundant.	Improving water quality, education → used for urban stream research	Not a big success → over designed → most run-off won't reach detention basin/wetland	Nothing known

	It is a combination of measures: rain garden, bioswale, rain barrels, porous pavers, constructed wetlands, etc.			
Little Sugar Creek Greenway, Charlotte, NC	Highly urbanized area Wetland combined with bioretention facility, costs: $100.000 - $500.000	Stream enhancements, greenway development, stormwater management + improving water quality	Urban development because of project, environmental education, community connectivity Stormwater management = success. Unclear if water quality has improved	Significant annual maintenance
Bowes Creem Country Club, Elgin, IL	Creating golf course communities in harmony with nature Stormwater recycling system + treatment train Golf course = buffer between residential enclaves and environmental corridor system. Bioretention facility, bioswale, porous pavers, curb-cuts + on-site wetlands for stormwater quilities.	Stormwater retention, green areas, feeling of well-being	Golf course drainage was designed to retain a 5-year storm within grass areas. End result: unique golf experience, big success. Golf course has provided recreational opportunity important to the health and quality of life for the community	$700.000 for maintenance in budget

	16 ha of wetlands preserved, 10 ha of wetlands mitigated/enhanced. Costs: $1.000.000 - $5.000.000			
South Los Angeles Wetland Park Site Plan, Los Angeles, CA	Wetland combined with bioretention facility, bioswale, porous pavers. 3.5 ha, costs >$5.000.000, entire park: $24.000.000 Location: 5 miles south of downtown Los Angeles	Creating more recreational open space, improving stormwater runoff quality, education, green areas, feeling of well-being, ecological value. The purpose is to assist the city in meeting total max. daily load requirements	Pollutant removal depends on site-specific conditions Bacterial removal effectiveness of 34-99% for different bacteria. Other benefits/objectives are a success	No information available
Ball Horticulture Corporate Campus, West Chicago, IL	Next to highly urbanized area Bioretention facility, rain garden, bioswale, restored wetlands for stormwater management +/- 16 ha (everything together)	Stormwater retention, recreation, green areas	All stormwater is retained on-site	Costs for maintenance have reduced over time Further information not available
Echo Park Lake, Los Angeles, CA	Densely populated urban area	Stormwater retention	After finishing the project, there were problems wit water	Minor increase from existing (?)

	Bioretention facility, rain garden, bioswale, wetlands. +/- 9 ha costs: $50.000 - $100.000		quality, however they are expected to be corrected within the project. A property value increase was reported Community is highly involved	
Sterling Stormwater Pond Improvements, Akron, OH	Stormwater pond, stormwater wetland, stream restoration Costs: $1.000.000 - $5.000.000	Stormwater retention	Sufficient stormwater storage capacity, decreased peak discharges by 30%, accommodate campus growth + development, enhance stormwater filtration functions, stabilize eroding stream banks, reduce nuisance geese, recreation, improved aesthetics	1.000 hours devoted to maintenance
Aurora Country Club, Aurora, IL	Shallow wetland at golf course Costs $50.000 - $100.000	Stormwater retention (wetland to collect + disperse excess rainfall) People should be able to play after a rain event Create a more sustainable + maintainable	Worked to solve immediate need of the gold course, while slowing off site drainage to a neighbouring park → 80% stormwater reduction Reduced impact to surrounding neighbourhood parks	15 hours annually for maintance

		environment	and open space including a path system that wold be impacted during rain events	
Wetland Conservation Area, New Albany, OH	5 ha stormwater treatment wetland, costs $1.000.000 - $5.000.000 suburban	Decrease peak discharges, increase water quality, filter pollutants, uptake nutrients, enhance habitat Education for high schools	Reduces peak discharges by 40%, reduce urban runoff pollutants by 25-75%, increased value of properties Environmental education is big success	100 hours annually
Carrol Village – A traditional Neighborhood Development, York Country, PA	Treatment train with rain gardens, infiltration areas, large stormwater wet pond, bioswales, wetland restoration Costs: $1.000.000 - $5.000.000	Achieve effective pollutant removal, sediment reduction, peak rate mitigation	System is able to effectively manage 95% of stormwater run-off generated by 2-year storm event on project site	Management guidelines for each component No exact information on maintenance available
Nancy Street Wetland Enhancement, Juneau, AK	Constructed wetland Costs: $100.000 - $500.000 ($31.000 for materials, $129.000 for labor)	Water purification; minimize iron floc, increase dissolved oxygen, improve water quality, eduction	No exact numbers on water purification, but seems a success Education = highly successful	20 hours annually
McConnell Springs Wetlands Demonstration Project, Lexington, KY	Urban nature preserve Constructed wetland with bioretention facility, bioswale, cistern, mechanical stormwater	Reduce non-point source pollution, provide demonstration to the public of the benefits of natural environments that	Functions successfully to control stormwater Demonstration project works successfully	No information available

	device as a demonstration technique for urban water quality management Costs: $100.000 - $500.000	provide water quality & quantity control Protecting environmental area		
Saylor Creek Watershed Imporvements, Ankeny, IA	Bioretention facility, bioswale, constructed wetland, lake forebay, riffle dams Costs: $1.000.000 - $5.000.000	Stormwater detention and water quality treatment for the City of Ankey, Iowa recreation	Can detain and treat 1,25 inch rainfall events Increased property value	40 hours
Saylor Grove, Philadelphia, PA	28 ha Stormwater treatment wetland Costs: $1.000.000 - $5.000.000	Address impact of urban runoff + bank erosion Water purification (70 mil. Gallons per year) Reduce peak stormwater flow rates + volumes	Succesfull	unknown
Everglades Nutrient Removal Project – Subtropical Constructed Wetland in South Florida	1544 ha surface flow constructed wetland. 5 cells containing a mixture of floating, emergent and submerged vegetation. Costs: $14.326.173 Prototype experiment	-Removal of mainly P from agricultural runoff before water flows to Everglades, which are P limited. -Also to remove mercury	Successful P removal Research value for other constructed wetlands	In some parts, natural occurring species are allowed

		-confirming & refining information from earlier prototype systems			
Banksia Street, O'Connor , Canberra, Australia	Febr. 2010, construction finished. 2 sections: deeper middle part, ephemeral zone which is more shallow. Ephemeral parts: inundated after rainfall, dry-out in summer 1250 m2 Ephemeral, dries out in summer	Stormwater management → improve water quality → improve sediments → increase urban biodiversity by planting → provide recreational, educational + volunteering opportunities to locals	Biodiversity levels have increased (waterbirds, macro-invertebrates, dragonflies, even a rare turtle species was found) Recreation, education and volunteering = success Challenge: controlling the presence of Gambusia fish	Mowing of dryland grass, desilting if needed, Nets to capture Gambusia fish	http://www.environment.act.gov.au/water/constructed_wetlands/banksia_st
Flemington Road Ponds, Canberra, Australia – UNDER CONSTRUCTION	Sullivan's Creek Catchment, Still under construction	Improve water quality in Sullivan's Creek Save 600.000 kilolitres of potable water per year Provide a diversified water source at a cheaper cost to end users Contribute to Water Sensitive Urban Design			http://www.environment.act.gov.au/water/constructed_wetlands map of area: see document "Sullivans Creek Catchment – Canberra – folder" Community is highly involved!!
The valley ponds,	Sullivan's Creek	Improved stormwater		Maintenance/site	http://www.environme

Gungahlin, Canberra, Australia – UNDER CONSTRUCTION	Catchment, Still under construction (construction began in Febr. 2012, nearly finished)	quality Retention of stormwater Increased urban biodiversity Provision of stormwater for irrigation Education + recreation		investigations: -heritage assessment, groundwater study, vegetation study -master plan developed by engineering consultants -plants were relocated to other places before construction. Exotic plants were removed, native plants were planted back after construction	nt.act.gov.au/water/constructed_wetlands map of area: see document "Sullivans Creek Catchment – Canberra – folder" Community is highly involved!!
Dickson and Lyneham Wetlands, Canberra, Australia – Construction finished, but not much results available	Sullivan's Creek Catchment Dickson wetland: construction has finished in Dec. 2011, no results available Lyneham wetland: open to public in April 2012. No results available Wetlands include seating, informal play areas, viewing spots, pedestrian paths, artwork, shade	Provide water quality improvements Play a role in flood detention Increase aquatic and terrestrial habitat in urban areas Provide an oasis in the suburbs Create new recreational, volunteering and educational opportunities Supply stormwater to irrigate playing fields	Dickson -community is greatly involved -indicators such as water bugs indicate that waterway = healthy -education is success -fauna has increased Lyneham: -Volunteers helped with planting - no results on performance known yet	Community helps with maintenance	http://www.environment.act.gov.au/water/constructed_wetlands map of area: see document "Sullivans Creek Catchment – Canberra – folder" Community is highly involved!!
Urrbrae Wetland, City of Mitcham,	Joint project of high school + city of Mitcham	Solve long standing flooding problem	Average annual runoff treated is between 300-	Since construction, modifications have been	WSUD ch. 13 pdf

Adelaide Region, Australia	Constructed in 1996, first filled in 1997 Max depth of ponds is 3 metres, ponds cover 3 ha, catchment area +/1 3.75 km2	Broaden environmental studies curriculum, address regular flooding on farmland → teaching wetland which also serves as runoff detention basin	400 megalitres -Reduces the frequency of local flooding -Removes suspended solids by sedimentation -Physically filters runoff through dense reed beds -Removes pollutants such as agricultural fertilisers and other chemicals which attach to soil particles and are removed by sedimentation and filtration -Destroys pathogens through exposure to the ultraviolet rays of the sun and feeding of zooplankton on pathogens -Filters out debris by operation of gross pollutants traps at inlets -Improves the quality of water entering Brownhill Creek and ultimately the Patawalonga basin -Provides a valuable research and teaching resource for the school and community	made to increase its performance. Among others inlet structures were enlarged and more trash racks were installed to improve collection of the organic litter and gross pollutants To enable regular cleaning out of the sediment settling ponds, the flow of water is controlled at the point of entry from the street by the installation of drop log gates that can be slid down to bypass the ponds that are being worked on.

			-Creates a protected habitat for locally indigenous flora and fauna		
Bearkout Creek instream Wetland, City of West Torrens, Adelaide Region, Australia	Breakout Creek = last 3.5 km section of River Torrens. Area was not available for community and recreational use, therefore transformed in a wetland. Construction completed in 1999	Create habitat and refuge areas for biodiversity Recreation Improve water quality	Improved water quality downstream, particularly under low flow conditions	No specific information	WSUD ch. 13 pdf
Warriparinga offstream Wetland, Bedford Park, Adelaide Region, Australia	Series of 4 ponds with shallow edges, 3 metre depth in centre. Permanent volume of wetland is 23 megalitres Second pond includes an island which serves as a refuge for birds and to create visual interest to wetland landscape Average annual flow of wetland is 8400 megalitres	Enhance the Warriparinga reserve and improve water quality of Sturt River	Native species not affected Wetland traps and removes contaminants including silt, nutrients, bacteria, heavy metals, oils and floating rubbish such as leaves and litter Wetland removes approximately 100 tonnes of sediment and 50 kilograms of phosphorus each year.	No specific information	WSUD ch. 13 pdf
Stormwater: Corindi Urban Stormwater Wetland, New South Wales	In operation since 2005/2005, 1 ha wetland, 15 ha catchment area, 2 ponds, +/1 33 cm deep,	Treat runoff pollutants and provide protection for a sensitive wetland located immediately	Good treatment capacity, to address particulate and dissolved nutrients.	Community involved in maintenance	http://www.waterandcarbon.com.au/stormwater/corindi-urban-stormwater-wetland-

	planting of native plants, Community involved	downstream from the development. Key challenges: variable flows and water quality, colloidal clays, protection of sensitive urban ecosystem, community concern, recreation	Produces clear water. Wetlands still in excellent condition.; host attractive plant species, mainly in the shallow part. Has become integrated part of local community, being frequently used for recreation		nsw
Stormwater: Slaters Creek Stormwater Wetlands Project, New South Wales	Stormwater wetland at site which has degraged due to historical clearing, the impact of stormwater flows and agricultural use. 2 ponds	Treat runoff in Slater's Creek, Lismore, NSW. Improve stormwater quality + habitat in the area Integrate with community aspirations, in corporate indigenous for site Function as community educational tool	Wetland system featured excess pathways, islands, bird viewing areas and a diverse range of plants and habitats No results on water quality	No information	http://www.waterandcarbon.com.au/stormwater/slaters-creek-stormwater-wetlands-project Dawson et al. pdf case study blz 4
Sewage Treatment: Aratula STP Treatment Wetlands – UNDER CONSTRUCTION	50 km south of Ipswich Township, 2 lagoons, effluent is disinfected with chlorine before discharged into adjacent creek. Flows: 45 kL/day, expected to increase to 200 kL/day in 2026 Construction stared in August 2012	Specifically designed for BOD and suspended solids, not for nutrients. The wetland will, however, filter nutrients out of the system. It is expected that the total N will be lowered to +/- 6 mg/L	Still under construction, so no results yet	Still under construction, so information on this could be provided	http://www.waterandcarbon.com.au/sewage-treatment/aratula-STP-treatment-wetlands-design-and-construct
Sewage Treatment:	Part of sewage treatment	Purify water, last stage	Sewage Treatment	No information	http://www.waterandc

South Lismore STP and Constructed Wetland	plant 5 (pre-existing) open ponds. Because of this, CW is not built in optimal configuration	after treatment in Sewage Treatment Plant	Plant has one of best performances in Australia, due to constructed wetland. Average total N: < 1mg/L Total P reductions of 70% and more		arbon.com.au/sewage-treatment/south-lismore-stp-and-constructed-wetland
Sewage Treatment: West Byron Integrated Water management reserve wetland	Sewage treatment plant 17 ha, 24 ha trial site with native wetland forest, 35 ha biodiversity wetland	Purify water; last stage after treatment in sewage treatment plant Reuse water Produce near-natural outflow water	Treatment wetlands provide higher and more consistent performance and a reduced risk profile by mitigating spikes and nutrient loads	Additional research is carried out t learn about methods to optimise plant establishment	http://www.waterandcarbon.com.au/sewage-treatment/west-byron-integrated-water-management-reserve-wetland
Sewage Treatment: Grenfell sewage treatment plan wetlands	Integrated wetland forest system 10 ha	Combining stormwater and wastewater treatment Ecological objects are important design aim	No information	No information	http://www.waterandcarbon.com.au/sewage-treatment/grenfell-sewage-treatment-plant-wetlands

Dutch case studies:

Constructed wetland	Description	Success factors	Threat	Opportunities
Capelle a/d Ijssel	Near a new built district of Capelle a/d IJssel, placed in 2005. Sub-surface horizontal flow constructed wetland. No monitoring or maintenance after construction. Now: revitalising constructed wetland (estimated costs: between 45.000 and 60.000 euros)	Now: recreational value for children, green value for district. Future: green value for district, educational value for citizens, water purification function	Not fenced: children could play in the filter. Citizens had no idea that there was a filter and of its functions There was no monitoring or maintenance plan	New design made by Witteveen & Bos. It involves a new filter, new maintenance plan and educational value
Houten (3)	3 filters near urban area. Surface flow constructed wetlands where water is actively pumped through. It consists of small ditches of 5m wide. Especially the filters in the northern area have a high ecological value (with red list species). This is mainly due to the fact that that it borders or a nature reserve. Wetlands are closed to public.	High water purification efficiency. Wetlands are multi-functional: water retention, ecological value, green image of city	Large number of geese; have to be actively removed from the area. Rushes were places for biomass production, but this was not successful. When ecological value becomes too high: problematic because of the flora & fauna law.	Maintenance: excavating biomass = expensive. They are working on a solution for this: if a solution is found, wetlands might become cost neutral
Soest	Constructed in 1998, monitoring since 2004. Motivation was nuisance of heavy rain events. Wetland consists of 3 parallel ditches + 2 pumps. Wetland is not accessible for citizens. Retention time = 48 hours. Wetland floods 1 or 2 a year. Water purification efficiency = 90%	Maintenance plan Wetlands were carefully designed, High efficiency is also achieved because filters floods max 2 times a year. It works really well for water retention (max capacity = 100.000 m3)	Sludge = big problem in filter. Sludge removal = expensive and there is a lot of sludge present in the filter.	City of Soest started with improving ecological value (ecoscan, kingfisher breeding areas, planting of extra rushes)
Hoogeveen	In this wetland, water purification is successfully combined with water retention, ecological value and recreation. Different stakeholders with different interests were involved:	Integrative approach Different compartments in filter. There is a lot of awareness among citizens. There's room for recreation.	Dat er een puntlozing komt die een groot effect heeft op het biologisch evenwicht. Ook is het nog onbekend wat precies de gevolgen zijn van waterretentie op waterzuivering.	Monitoring could have been better; but they are working on a solution. Maintenance was underestimated, which costed a lot of money, especially in the beginning. Muskrats form a

	the sewer system of the city had to be improved, the area north of Hoogeveen was appointed as urban fringe zone, the ecological connection zone lays near the city and upstream water retention was needed to prevent water surpluses from reaching the city of Meppel. The constructed wetland of ca. 6 hectares is the result of an integrative approach where all different interests have been taken into account. A maintenance and design plan was made.		Possible danger = what happens when point discharge happens; will the constructed wetland be able to purify the water? And what will happen to the ecology of the wetland + water retention capacity?	major problem.
Leidsche Rijn	Pilot study. Objective was to filter P from surface water. Vertical flow constructed wetland, fill and drain principle (according to Waterboard). Fe and Ca were added for P removal. Primary function of vegetation was to prevent clogging.	Filter should (in theory) be able to purify water. Filter was unsuccessful.	High requirements (a lot of P needed to be filtered from relatively clean water, without addition of chemicals, sustainable, fitting in a natural environment, not industrial looking, as cheap and compact as possible)	A better design plan: water was not evenly distributed over the filter + retention time (1 hour) was short
Amsterdam Sarphatipark	Vertical flow constructed wetland, designed by Ecofyt. Water from 4 big ponds is filtered in constructed wetland.	Technically well designed, problems such as soft (sub)soil were tackled by using Bims to achieve neutral weight. Wetland worked after construction. Quality of the water improved and Botulism disappeared from the area. Tried to incorporate different interests in design and maintenance plans (city of	Constructed in 2004, but is not working anymore. Poles used to build the wetland are rotten and some other parts of the wetland are also prone to destruction. Maintenance: difficult. It's shared between Waternet and the city of Amsterdam, different districts also form a problem: the different districts (separately) don't have enough work for a specialist.	Create a higher awareness among citizens, so they won't feed the birds (bird droppings pollute the wetland) Some parts have to be more sustainable: a plan to achieve this is made by Ecofyt (costs: 38.000) but that's too expensive for the city of Amsterdam Maintenance should have an integrative approach.

		Amsterdam, neighborhood, waterboard		
RWZI Land van Cuijk	Water harmonica, post-treatment near sewage treatment plant. Surface flow constructed wetland. +/- 4 ha. Total of 8 ditches. Every day: monitored. Regular maintenance (although not according to a set up plan).	Ecological value (birds). Right after construction: objectives achieved (more oxygen in the water, composition of suspended solids changed, N and P removed)	Wetland is saturated with P. water is not flowing evenly through the filter:. Because of this, water depth is fluctuating. When water > 0.5 for a longer period: reed dies. Filter is not working in winter. Biomass production was unsuccessful.	Revitalisation is needed. For now: sandfilter is added for extra nitrate removal.
IBA's Zuiderzeeland	100 IBA's with constructed wetlands (counted as one in this research) maintenance = once a year. Also regularly monitored.	Biologically robust. Costs are not too igh Constructed wetlands perform better than the alternative (= compact systems).	Money is needed (final objective of 222 installed constructed wetland IBA-systems is not achieved)	
Kristalbad	40 ha, between Hengelo and Enschede. Different interest: post-treatment after sewage treatment plant, water retention, ecological value, spatial quality for landscape, recreation. Pilot with floating macrophytes Combination with other functions.	Integrative approach + maintenance and monitoring plan.	June 2013: not fully functioning (yet), however according to waterboard filter = success	June 2013: not fully functioning (yet), however according to waterboard filter = success
RWZI Soerendonk	Post-treatment (after sewage treatment plant). Combination with other measures. Waterharmonica. Ecological value, water retention	Learned from mistakes of previous waterharmonica's. ➔ Sand filter was incorporated in initial design plan to enhance nitrate reduction ➔ Clear maintenance plan incorporated in design	Project recently started; no known (yet)	Project recently started; no known (yet)