Investigating the suitability of constructed wetlands for the treatment of water for fish farms

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WAGENINGEN UR
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Centre for Development Innovation

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Start: 01 January 2012
Completed: 31 December 2014

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This study was funded by the Dutch Ministry of Economic Affairs
(project numbers BO-10-011-124; BO-10-001-225; BO-27.02-001-007) and Baledna

Centre for Development Innovation
Wageningen, March 2015

Report CDI-15-079

Fish Producers and
Exporters Association
FPEA

Van der Heijden, P.G.M., F. van Dien, D. A. El-BeshBishi, 2015. *Investigating the suitability of constructed wetlands for the treatment of water for fish farms*. Centre for Development Innovation, Wageningen UR (University & Research centre). Report CDI-15-079. Wageningen.

This report describes a collaborative project between CDI (Wageningen UR), Ecofyt and a private fish farm in Egypt that aimed to test the effectivity of a Constructed Wetland (CW) to reduce the levels of pesticides and heavy metals of drainage canal water. First a study of the scientific literature regarding the effectiveness of CWs as remover of pesticides and heavy metals from waste water was carried out. Next a pilot CW was constructed on a private fish farm in Kafr El Sheikh province, Egypt. The level of pesticides and heavy metals in tilapia grown in drainage canal water that was treated by the pilot CW was compared with the level in tilapia fish grown in untreated drainage canal water. The absence of pesticides and the very low levels of only some heavy metals in the untreated drainage canal water at the moment of sampling and the low levels or absence of such contaminants in the fish made it impossible to draw conclusions about the effectiveness of the pilot CW. Further and better controlled studies are needed.

Keywords: constructed wetland; engineered wetland; drainage water treatment; fish culture; pesticides; heavy metals.

This report can be downloaded free of charge from www.wageningenUR.nl/cdi ("publications").

Report CDI-15-079

Photo cover: Pilot constructed wetland in Kafr El Sheikh by Peter G.M. van der Heijden

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Acknowledgements

This project was initiated by the Netherlands Agricultural Counsellor in Cairo, Dr. Hans van der Beek, in collaboration with the Fish Producers and Exporters Association (FPEA). It was financed by the BO (Policy Support) program of the Netherlands Ministry of Economic Affairs. The implementation was a collaborative effort of the owner of fish farm Baledna, Mr Diaa El BeshBishi and Ecofyt (Frank van Dien) and the Centre for Development Innovation (CDI, Wageningen UR) that coordinated the project. The authors would like to thank Mr Salah Taher who as liaison officer of FPEA facilitated the contacts with various FPEA officials and others; WorldFish and especially Dr Ahmed Nasr Allah who assisted with storage and submission of samples at the laboratory of QCAP. We gratefully acknowledge the assistance of Mr Hakiem El-Wageih (Plant Systems) with the clearing of equipment through the Egyptian Customs.

Executive summary

This report describes a collaborative project between CDI (Wageningen UR), Ecofyt and a private fish farm in Egypt that aimed to test the effectivity of a Constructed Wetland (CW) to reduce the levels of pesticides and heavy metals of drainage canal water. First a study of the scientific literature regarding the effectiveness of CWs as remover of pesticides and heavy metals from waste water was carried out. Next a pilot CW was constructed on a private fish farm in Kafr El Sheikh province, Egypt. The level of pesticides and heavy metals in fish grown in drainage canal water that was treated by the pilot CW was compared with the level in fish grown in untreated drainage canal water. The absence of pesticides and the very low levels of only some heavy metals in the untreated drainage canal water at the moment of sampling and the low levels or absence of such contaminants in the fish made it impossible to draw conclusions about the effectiveness of the pilot CW. Further and better controlled studies are needed.

1 Introduction

Fish is the cheapest source of animal protein in Egypt and important for the country's food security. In the past two decades the aquaculture sector of Egypt has grown rapidly. With a production approaching 1,000,000 tons in 2013 Egypt is by far Africa's largest producer of farmed fish. Thanks to this production growth the availability of fish increased from 15.2 kg/person in 2002 to 19.1 kg/person in 2012 (GAFRD, 2012). About 74% of this is produced in Egyptian fish farms.

The Government of Egypt is very concerned with the limits to the amount of fresh water available to the nation. Laws originating from 1983 prohibit the use of irrigation water (Nile water) for grow-out fish farms. Such farms are allowed to use saline water or water from the drainage canals that contain water flowing from the regions with irrigated agriculture to the lakes in the northern section of the Nile Delta and the Mediterranean Sea. The majority of the Egyptian fish farms are located in the northern and eastern parts of the Nile delta (near Lake Borullus, Lake Mariut, Lake Edko and Lake Manzala), in Fayoum and in the newly reclaimed desert regions bordering the Nile Delta. Total area covered by fish farms is approximately 179,000 ha (FAO 2010). An analysis of satellite images resulted in an estimate of the total pond surface of 104,000 ha in the Nile delta area only (ALTERRA, 2010). The majority of these farms rely on drainage canals as the source of water to fill ponds and refresh pond water. This reliance carries the risk of raising fish in water that is contaminated with agro-chemicals and/or heavy metals. If the contamination is below lethal levels the health and growth of the fish is not immediately affected, but part of the chemicals may accumulate in the fish tissues, especially in certain organs and fat deposits. This may pose a long-term health risk for consumers. There is no regular and systematic sampling and analysis of fish to assure food-safety for the consumers (QCAP staff, personal communication, 2011). Incidental sampling of caught and farmed fish from consumer markets show a high incidence of pesticides and heavy metals in fish, often above the Egyptian standards (Khorshed et al, 2011). Egypt has not submitted a comprehensive residue monitoring program for aquaculture products to the European Union which is one of the requirements for the export of farmed freshwater fish from Egypt to the EU (Goulding & Kamel, 2013).

Egyptian fish farmers would like to grow a product that is free from contaminants, safe for all consumers and that can also be exported. As long as the Egyptian laws prohibit the use of irrigation (Nile) water for the grow-out of freshwater fish, most farmers will in the years to come continue to rely on water from the drainage canals.

In 2011 the Fish Producers and Exporters Association (FPEA), an organisation of approx. 30 Egyptian fish farmers, raised the idea to investigate and test if constructed (engineered) wetlands are effective as filters that remove hazardous chemicals from the drainage canal water before the water is used to fill the fish ponds. A wetland system that is specifically engineered for water quality improvement as a primary purpose is called a Constructed Wetland (CW) System. Through the artificial creation of a wetland ecosystem, some of the physical, biological and chemical processes of natural wetlands can be replicated, thereby mimicking the capacity of natural wetlands to ‘treat’ wastewater by removing (or at least ‘locking up’) sediment, nutrients and toxins, including heavy metals and pesticides. There are to our knowledge no cases of commercial / private fish farms in Egypt that treat the incoming or outgoing water with CWs.

2 Objective of the project

Testing the suitability of the Constructed Wetland (CW) technique to improve the quality of drainage canal water became the objective of a project that was co-financed by the Policy Support program of the Dutch Ministry of Economic Affairs and that was executed between January 2012 and December 2014.

In addition to testing the removal of pesticides and heavy metals, the project also aimed to explore if CWs can be used to treat and re-use the fish farm's waste water and make it suitable for re-use on the fish farm. If effective in this way, the CWs can contribute to reduction of the amount of water that is used by fish farms (contributing to 'more crop (fish) per drop').

The major target group of the project are owners and managers of fish farms, of which there are thousands in Egypt.

3 Activities undertaken

3.1 Literature study

In May 2012 a study was commissioned to Van Hall Larenstein University of Applied Sciences to review the literature on the capacity of Constructed Wetlands to remove pesticides and heavy metals as well as the factors that affect the effectivity of CWs to remove such substances. The review took place between May 2012 and June 2013. The report “Constructed wetland and aquatic treatment systems for fish farms in Egypt - Desk study report” by Geert Truijen and Peter G.M. van der Heijden was completed in August 2013. The report describes the mechanisms and processes that enable constructed wetlands to remove heavy metals and pesticides from waste water. It examines what factors have an influence on the effectiveness of constructed wetlands to treat waste water containing such pollutants and shows the consequences for the design and operation of constructed wetlands. The desk study focusses on free surface flow wetlands and aquatic treatment systems because these types are better able to treat the large volumes of water that are required to fill and maintain water levels of fish ponds as operated in Egypt. The literature study showed that CWs commonly obtain a heavy metal removal efficiency in the order of 30 to 60%, but can reach 80 to 90%. Pesticide removal by CWs is typically in the order of 40 to 99%, but some compounds show much less removal. The presence of decaying organic matter (detritus) in the CW was identified as an important factor contributing to the removal. On January 15, 2015, the report of the literature study had been downloaded over 460 times from the Wageningen UR Library website.

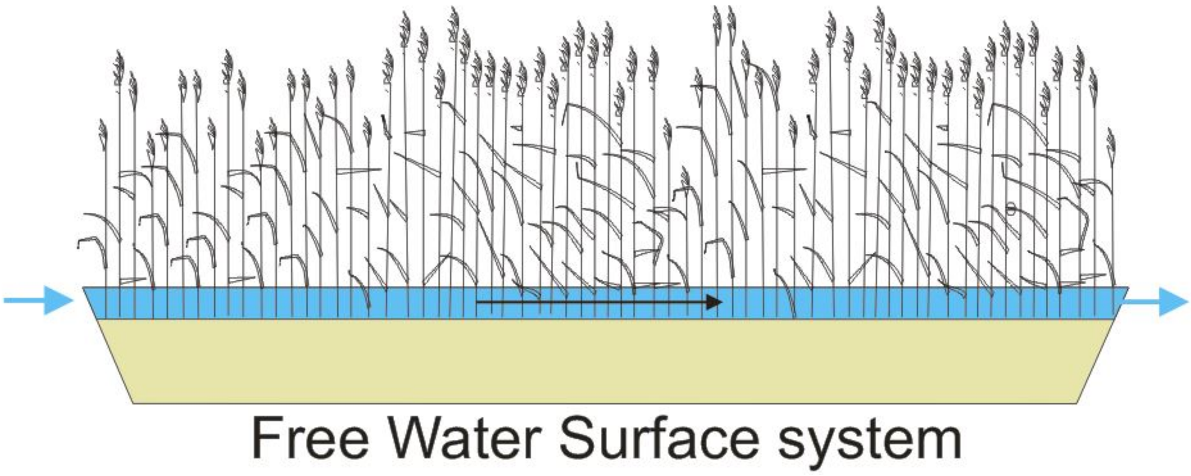
3.2 Selection of type and location of the pilot CW

In consultation with the FPEA officials two possible sites for a pilot CW were selected and visited in July 2012. In one site the fish ponds are owned by members of the Fayoum Fish Farmers Cooperative, the other site is Kafr ElSheikh province (northern Nile delta). In both sites Board members of the FPEA own one or more fish farms. The fish farms near Fayoum are located between Lake Rayan 1 (Wadi el Rayan1) and Lake Rayan 2 (Wadi el Rayan 2). The water source of the fish farms is drainage water from Fayoum that has stayed already for a long period (years?) in Lake Rayan 1. As result of this long retention time the water leaving this lake is of good quality and with low levels of contaminants. On the other hand, the water supply of the farms in Kafr El Sheikh is a drainage canal from Pump 7 with water that flows directly from agricultural lands situated in the central Nile delta. This water is expected to be more contaminated with agricultural and other chemicals than the water from Lake Rayan 1. For this reason, and for the availability of a suitable site for the pilot CW on privately owned fish farm territory, the fish farm ‘Baledna’ in Kafr El Sheikh was selected as the site for the pilot Constructed Wetland. Construction of the pilot CW was planned to start in 2012 but was delayed until March - May 2013 due to the social and political unstable situation in Egypt.

Photo 1 *Fish pond of Fayoum Fish Farmer - Cooperative member*
Photo 2 *Some of the fish ponds of Baledna farm, Kafr El Sheikh*

(Photos: P.G.M. van der Heijden)

There are several types of constructed wetlands used to treat waste water. The types can be separated in wetlands in which the water that needs to be treated freely flows as visible surface water ('surface flow' or "Free water surface", Figure 1a) and the types in which the water that needs to be treated flows through a sediment (sand, gravel) and is mostly invisible ('sub-surface flow', Fig. 1b).



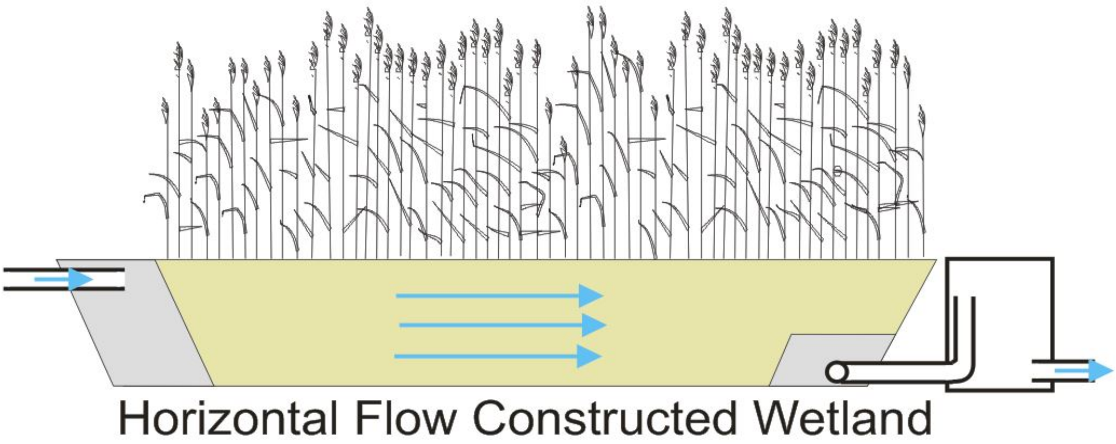


Figure 1 *Side-view of a) Surface flow (upper) and b) Sub-surface horizontal flow (lower) wetland*
source: © ECOFYT.com

In general the surface flow constructed wetlands can treat a larger volume of water/m^2/day than the sub-surface flow type but the efficiency of this type of engineered wetlands in terms of % removal of contaminants is less. The volumes of water needed to fill up fish ponds or partly renew the water of such ponds are large. Hence surface-flow constructed wetlands emerged as the most suitable type for fish farms in Egypt. This was reinforced after discussion with scientists of the Drainage Research Institute (DRI, Ministry of Water Resources and Irrigation, Egypt) and a visit to the Lake Manzala Engineered Wetland (LMEW) that is part of the Manzala Water Research Station of DRI. LMEW became operational in 2004 and has since treated 25,000 m^3 per day of water from the Bahr El Baqar Drainage Canal. The LMEW consists of a pumping station, 2 sedimentation basins plus 10 surface flow wetlands, each wetland measuring 250 x 50 m. Its efficiency as a treatment device has been described by El-Sheikha et al (2010).

Photo 3 & 4 *Pumping station and one of the surface flow constructed wetlands of Lake Manzala - Engineered Wetland* *(photos: P.G.M. van der Heijden)*

The treated water is used to fill fish ponds in which mullet is raised in an extensive way (without supplemental feeding). The income generated from the sales of fish is used to cover the LMEW operating costs. Scientists of DRI compared contaminant levels in the flesh of fish raised in water treated by the LMEW with the levels of fish raised in un-treated Bahr El Baqar Drainage Canal water. Theesults (Table 1) show significantly lower levels of the heavy metals in the flesh of fish raised in treated water. Thes results, the observations at the Manzala Water Research Station and the discussions with the scientists of the DRI have been helpful in the design of the pilot CW that was built on the fish farm 'Baledna' in Kafr El Sheikh.

Table 1
Average of heavy metals concentration (mg/kg) in the muscles of the treated-water fish and the untreated-water fish.

Metal		Egyptian Limit	Treated-water fish	Untreated water Fish
Aluminium	Al	NA	0.403	-
Cadmium	Cd	0.10	0.10	0.328
Cobalt	Co	NA	0.0002	1.3
Chromium	Cr	NA	0.0166	-
Copper	Cu	20	0.0146	8.4
Iron	Fe	NA	0.6084	130
Manganese	Mn	NA	0.05	-
Nickel	Ni	NA	0.0072	-
Lead	Pb	0.1	<0.001	2.8
Zinc	Zn	50	0.104	-

Source: El-Hawary, A.M. (2010) Reuse of treated wastewater for fish farming in Lake Manzala.

In 2013 attempts were made to start a small research project at the Lake Manzala Water Research Station to be co-funded by this BO project. The objective of the research project was to duplicate the test with the pilot CW at the private fish farm in Kafr El Sheikh: raise tilapia in water treated by small, newly constructed engineered wetlands of the same type as the pilot CW and compare contaminant levels in the fish with the levels in tilapia grown in untreated drainage canal water. Unfortunately, the socio-political unrest in Egypt in the spring & summer of 2013 and the effects on DRI and the Lake Manzala Water Research Station prevented such a collaborative research to take off.

3.3 Design and construction of the pilot CW at Baledna fish farm, Kafr El Sheikh

A second visit to Baledna fish farm by the constructed wetland expert of Ecofyt and P.G.M. van der Heijden took place in December 2012. The part of the farm that was available for installation of a pilot CW in July 2012 was no longer available but at another site of Baledna a 1100 m^2 pond could be made available for conversion to constructed wetland. With this pond as starting point a design for the pilot CW, list of equipment, materials & works and a guide describing the CW principles and operating procedures were made (Appendix 1 and 2). The design, related works and costs were discussed with the owner of Baledna and the FPEA board member/ liaison officer. Agreement was reached and a contract between the owner of the fish farm and CDI was drafted and signed. With help of Ecofyt two water flow meters, two electric pumps and smaller materials were purchased and shipped to Egypt.

The CW proposed to be constructed as pilot CW was of the surface flow type and would have a depth of 30 cm. In May 2013 Ecofyt provided a detailed construction guide for the pilot CW plus three days of assistance on location with the construction. Because during former fish growth cycles pollutants could have accumulated, the sediment on the pond bottom was removed and the bottom was covered with a 8 cm layer of clean sand. Next the pond was divided in two sections by means of a low levee: one section was planted with shoots of reed (*Phragmites spp*.) and in the other section water hyacinths (*Eichhornia crassipes)* were placed. Reed shoots and water hyacinths were collected from nearby canals. Both plant species are known to play a beneficial role in the treatment of waste water. In both sections bundles of rice straw were placed in the sand to compensate for the lack of decaying plant material on the bottom in the early stages of the engineered wetland operation when the amount of reeds and water hyacinths growing in the filter is still small. A hydraulic retention time of 4 days was chosen which is equivalent to an average flow of 72 m^3 of drainage canal water per day through the wetland. The clean, treated water leaving the CW is used to fill the fish pond adjacent to the pilot CW. During times this pond requires no input water the CW effluent is used in the tilapia hatchery of Baledna that is located close to the pilot CW.

To enable the Dutch advisor to assess if the system operated as designed, the farm owner was asked to send a photo of the electric switch board and of the water volume meters every month.

Appendix 1 shows a sketch of the starting situation and of the design of pilot CW.

Photo 5-11 show various stages of the pilot CW construction. Photo 12 shows the pilot CW in operation 1.5 years after its construction.

Photo 5 *Pond before transformation into pilot CW* *(Photo: P.G.M. van der Heijden)*
Photo 6 *Installing the water outlet system* *(Photo: F. van Dien)*

Photo 7 *Installing the water outlet system*

Photo 8 *Installing the water inlet system (Photos: F. van Dien)*

Photo 9&10 *Newly constructed pilot CW with section planted with reed shoots and section with floating water hyacinths (Photos: P.G.M. van der Heijden)*

Photo 11 *Pilot CW water inlet structure*

Photo 12 *Pilot CW 1.5 years after construction. The planted reed has grown almost 3 m high and needs cutting (Photos: P.G.M. van der Heijden)*

4 Results

4.1 Operation of the pilot constructed wetland

The first year of operation of the pilot Constructed Wetland at Baledna fish farm was not without problems. The electric pump at the inlet broke down and was replaced by the farm owner. (Later the pump was quickly repaired by the Netherlands consultant). Also the replacement pump broke down and the farm owner replaced it with a new, stronger electric pump. This pump was still in operation in December 2014. One of the water volume meters was stolen but could be recovered after it was put up for sale by the thief in Kafr El Sheikh city. Later, both meters stopped working properly and were repaired and cleaned two resp. four times by technical staff of the irrigation authorities in Kafr El Sheikh.

Although he was reminded several times, the owner of the fish farm where the pilot CW was installed failed to send photos of the electrical switch board and of the water volume meters as was initially agreed. Because the water volume meters had been removed, repaired and cleaned several times no reliable information could be obtained from the meter readings during the farm visits by the Netherlands partners in this project. The lack of reliable data regarding the pump operation frequency, the water volumes that were pumped through the pilot CW as well as the low levels of heavy metals and pesticides in the drainage canal water (see par. 4.2) makes an assessment regarding the type and design parameters of the pilot CW (i.e. CW dimensions, hydraulic retention time, effectiveness of the plant species placed in the pilot CW, etc.) nearly impossible. Because of this lack of information and clear conclusions regarding the effectiveness of the pilot CW, the planned dissemination of the results to Egyptian fish farmers by means of an on-site workshop was cancelled.

4.2 Determining the effectiveness of the pilot CW for removal of heavy metals and pesticides

4.2.1 Methods used

The water of the pilot CW was initially used in the tilapia hatchery of Baledna which is located beside the CW. In September 2013 the fish pond adjacent to the CW (pond A2) was filled with water treated by the pilot CW and stocked with fingerlings of Nile tilapia (*Oreochromis niloticus*). During the whole culture cycle (from stocking to harvest) the pond water was supplemented with water treated by the pilot CW except during one period of several weeks when the inlet pump was out of order and untreated water was used to partly refresh the pond water. During the fish culture cycle the treated water was also used in the tilapia hatchery. The fish culture cycle itself took place without major problems. Harvest of pond A2 was scheduled for spring / summer 2014 but was postponed until the end of October 2014 because the farm owner waited for the improvement of market prices of tilapia.

Sampling and analysis of fish, water and fish feed took place twice (December 2013 and October 2014). Both times untreated water of the drainage canal, the treated water flowing out of the CW, the fish raised in pond A2 (filled with treated water) and the feed given to the fish were sampled. For comparison also tilapia raised in a pond filled with untreated drainage canal water (pond A5 and pond A6) were sampled and analysed. The water samples were stored in a refrigerator. The fish samples were transported on ice and stored the same day in a freezer until the day the analysis in the laboratory took place. World Fish office in Cairo assisted with the storage of the samples and transport and submission of the samples to the laboratory.

Photo 13&14 *Harvest of Pond A2* *(Photos: D.A. El-Beshbishi)*

Photo 15&16 *Harvested tilapia prepared for transport to the market* *(Photos: D.A. El-Beshbishi)*

Photo 17&18 *Fish samples prepared for transport to Cairo for analysis by QCAP laboratory*

(Photos: D.A. El-Beshbishi)

At the time of sampling the tilapia in pond A2 had lived 3 resp. 14 months in the pond and had an average weight of 20-50 grams (December 2013) resp. 500 gr (end October 2014). The fish from the pond with untreated water that was sampled for comparison had lived 8 months in these ponds and weighed approx. 300 gr.

Samples were analysed by the QCAP Central Laboratory of Residue Analysis of Heavy Metals and Pesticides in Food (Ministry of Agriculture) located in Dokki, Giza (Egypt). This laboratory is specialised in and certified for the analysis of food samples. Food producing companies often have their products analysed by QCAP before these are exported. The concentration of over 400 commonly occurring pesticides in the samples were analysed using the multi-residue method for water analysis which determines levels of organohalogen, organonitrogen, organohosphorous and some pyrithroid pesticide residues using LC-MSMS and GC-MSMS. The concentration of the metals mercury, manganese, lead, copper, cobalt, chromium, cadmium and arsenic in the water samples was determined using Atomic Absorption Spectrometry. Pesticides and heavy metals are known to accumulate in fish and other organisms especially in organs like livers. For this reason the livers and the flesh (meat) of the fish samples were analysed separately. The concentration of pesticides in fish feed and fish tissue samples were analysed according to the 'Quick and Easy Method (QuEChERS) for determination of Pesticide residues in Foods' using LC-MSMS and GC-MSD. The concentration in fish tissue and feed samples of the metals mercury, manganese, lead, copper, cobalt, chromium, cadmium and arsenic were determined using Atomic Absorption Spectrometry after high pressure microwave digestion.

4.2.2 Results

The results of the analysis of water, fish tissue and fish feed samples are summarised in Table 2 and 3.

With regard to contaminant levels in water: the effectivity of the pilot CW to remove pesticides cannot be determined due to the general absence of pesticides in the drainage canal (inlet) water. The effectivity of the pilot CW as filter for heavy metals can be deducted only from the analysis of water sampled in December 2014, where the levels of the heavy metals cadmium and arsenic in the outlet water is lower than of the inlet water. However, the opposite is the case for manganese of which the concentration in the outlet water is higher than in the inlet water. This could perhaps be explained by the release of cadmium from the sand that was used to cover the bottom of the pilot CW. Another possible explanation is the fish feed which had approx. 46 mg/kg of manganese (average content in two samples, Table 2 and 3).

With regard to contaminant levels in the fish: only in the liver of fish from ponds with untreated water a pesticide (0.04 mg/kg of ethoxyquin) was detected. Because no pesticides were detected in the flesh or liver of fish grown in treated water this is an indication towards the effectivity of the pilot CW to remove pesticides. In 2013 the only heavy metal detected in fish was copper in the liver, with a somewhat higher level found in the livers of fish raised in untreated water than in livers of fish raised in treated water. The same is the case in the livers of fish sampled in October 2014. The same feed was given to the fish in all ponds that were sampled and the analysis shows that the feed was also a source of copper. But if the feed was the only or main contributor to the copper levels in the fish liver, we would expect no difference in concentration in the fish from the different ponds. Manganese was also present in both fish feed samples but this metal does not seem to have accumulated in the livers or flesh of the fish.

Table 2

Results of analysis of fish (flesh and liver), water and fish feed samples.

Sampled: December 16, 2013. Analysed: December 22 - 24, 2013

	Pesticides, mg/kg				**Heavy Metals, mg/kg (water samples: mg/L)**							
	Diazonon	**Malathion**	**Ethoxyquin**	**Chlorpyrifos**	**Mercury**	**Manganese**	**Lead**	**Copper**	**Cobalt**	**Chromium**	**Cadmium**	**Arsenic**
Water inlet Constructed Wetland	no pesticide residues detected				n.d.	< LOQ	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Water outlet Constructed Wetland	no pesticide residues detected				n.d.	< LOQ	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Tilapia Pond A2, flesh	no pesticide residues detected				n.d.	< LOQ	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Tilapia Pond A2, liver	no pesticide residues detected				n.d.	< LOQ	n.d.	28.2	n.d.	n.d.	< LOQ	n.d.
Tilapia, Pond A6, flesh	no pesticide residues detected				n.d.	< LOQ	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Tilapia, Pond A6, liver	no pesticide residues detected				n.d.	< LOQ	n.d.	33.3	n.d.	n.d.	< LOQ	n.d.
Fish Feed	0.01	0.03	0.02	0.03	n.d.	37.9	1.03	24.5	n.d.	31.5	0.08	n.d.

Note: n.d. = not detected

< LOQ = below the limit of quantification

Table 3

Results of analysis of fish (flesh and liver), water and fish feed samples.

Sampled: October 29, 2014. Analysed: November 24 & 26, 2014

	Pesticides, mg/kg					Heavy Metals, mg/kg (water samples: mg/L)							
	Lambda-Cyhalothrin	**Malathion**	**Ethoxyquin**	**Sulfur**	**Chlorpyrifos**	**Mercury**	**Manganese**	**Lead**	**Copper**	**Cobalt**	**Chromium**	**Cadmium**	**Arsenic**
Water inlet Constructed Wetland	no pesticide residues detected					n.d.	< LOQ	n.d.	n.d.	n.d.	n.d.	0.34	< LOQ
Water outlet Constructed Wetland	no pesticide residues detected					n.d.	0.13	< LOQ	n.d.	n.d.	n.d.	0.00037	0.001
Tilapia, Pond A2, flesh	no pesticide residues detected					< LOQ	< LOQ	n.d.	< LOQ	n.d.	n.d.	n.d.	n.d.
Tilapia, Pond A2, liver	no pesticide residues detected					< LOQ	< LOQ	n.d.	19.2	n.d.	n.d.	< LOQ	n.d.
Tilapia, Pond A5, flesh	n.d.	n.d.	< LOQ	n.d.	n.d.	< LOQ	< LOQ	n.d.	< LOQ	n.d.	n.d.	n.d.	n.d.
Tilapia, Pond A5, liver	n.d.	n.d.	0.04	n.d.	n.d.	< LOQ	< LOQ	n.d.	29.4	n.d.	n.d.	< LOQ	n.d.
Fish Feed	0.03	< LOQ	0.13	0.12	0.31	n.d.	55.4	n.d.	11.2	n.d.	n.d.	0.024	n.d.

Note: n.d. = not detected

< LOQ = below the limit of quantification

5 Conclusions and lessons learnt

The absence of pesticides and few heavy metals observed in very low concentrations in the drainage canal water makes it difficult to draw conclusions regarding the effectiveness of the pilot CW as a filter for heavy metals and pesticides. The consistently lower levels of copper in the fish from ponds with treated water is the strongest indication that we have obtained concerning the effectiveness of the pilot CW.

One should be careful with drawing strong conclusions from our data regarding the quality of the drainage canal water near Pump 7 at Kafr El Sheikh. The data are a snapshot of the situation on the moment of sampling; the water quality could be very different at different moments or in other seasons. However, the contaminant levels found (or better: not found) in the fish tissue reflect also the exposure to contaminants in the past. The absence of the pesticides in fish tissue, the presence of only low concentrations of copper (and absence of the other heavy metals that were tested) in the fish that was during 8 months raised in untreated drainage canal water is an indication that the fish were probably not exposed during this period to high levels of these contaminants over a longer period. If they had been exposed to significant levels over a longer period this would probably have led to some residues in their flesh or liver.

A Hydraulic Retention Time of 4 days (i.e. volume of daily water inlet of 72 m^3) was chosen for the pilot CW during the first fish production cycle. The daily pump operation time was chosen and set to pump this volume of water into the CW. But because we did not obtain the water meter readings we are not sure of the real water volumes that passed through the filter. Also the periods of absence of the water volume meters make it impossible to estimate the volumes of water that passed the CW from the readings obtained during the farm visits. Because of the lack of data we cannot say whether the retention time of 4 days was too short, too long or exactly right. If the retention time could be reduced to 2 days without compromising the contaminant removal efficiency of the CW, the capacity (= volume of water to be treated per day by a CW) would be double. A better controlled trial is needed to establish the optimal retention time of a surface flow CW in Egypt.

To fill a feddan (= Egyptian name for surface unit, equal to 4200 m^2 or 0.42 ha) of ponds with an average depth of 1 m a volume of 4200 m^3 of water is needed. If the pond needs to be filled in 5 days, a volume of 840 m^3 of water/day is needed. In order to treat this amount with a surface flow Constructed Wetland of the type tested as a pilot in Kafr El Sheikh (with 30 cm water depth and Hydraulic Retention Time of 4 days) a CW with a surface of 11,200 m^2 is needed. When a HRT of 2 days proves to give satisfactory levels of removal of contaminating compounds only half this size (5600 m^2) is needed. From this estimate one should not conclude that a fish farm needs at least the same size of CW as the total surface of the ponds: the effluent from the CW can be used to fill one pond after another. To enable the filling with treated water of one pond after another the CW needs to be located at a strategic spot in the farm, probably close to the site where the water enters the farm.

6 Recommendations

1. It is advised to sample and analyse the water and fish raised in water from Pump 7 drainage canal in Kafr El Sheikh also in the summer months (when agricultural activity and pesticide use are more intense) to obtain a better picture of the water quality situation.
2. Tests should be done under better controlled conditions to determine if a shorter Hydraulic Retention Time (3 or 2 days) would also lead to a satisfactory level of treatment. Prove that a shorter retention time (i.e. higher treatment capacity) of the CW also gives satisfactory treatment would reduce the farm area that needs to be allocated to the water treatment system and would make installing a Constructed Wetland more attractive.
3. Based on the tests recommended above, an estimate should be made of the ratio fish pond surface area : constructed wetland surface area for a fish farm that relies on drainage canal water and that needs to have all input water treated with a Constructed Wetland. For fish farm owners this ratio plus estimated construction costs will be important information when considering whether to install a CW on the farm.

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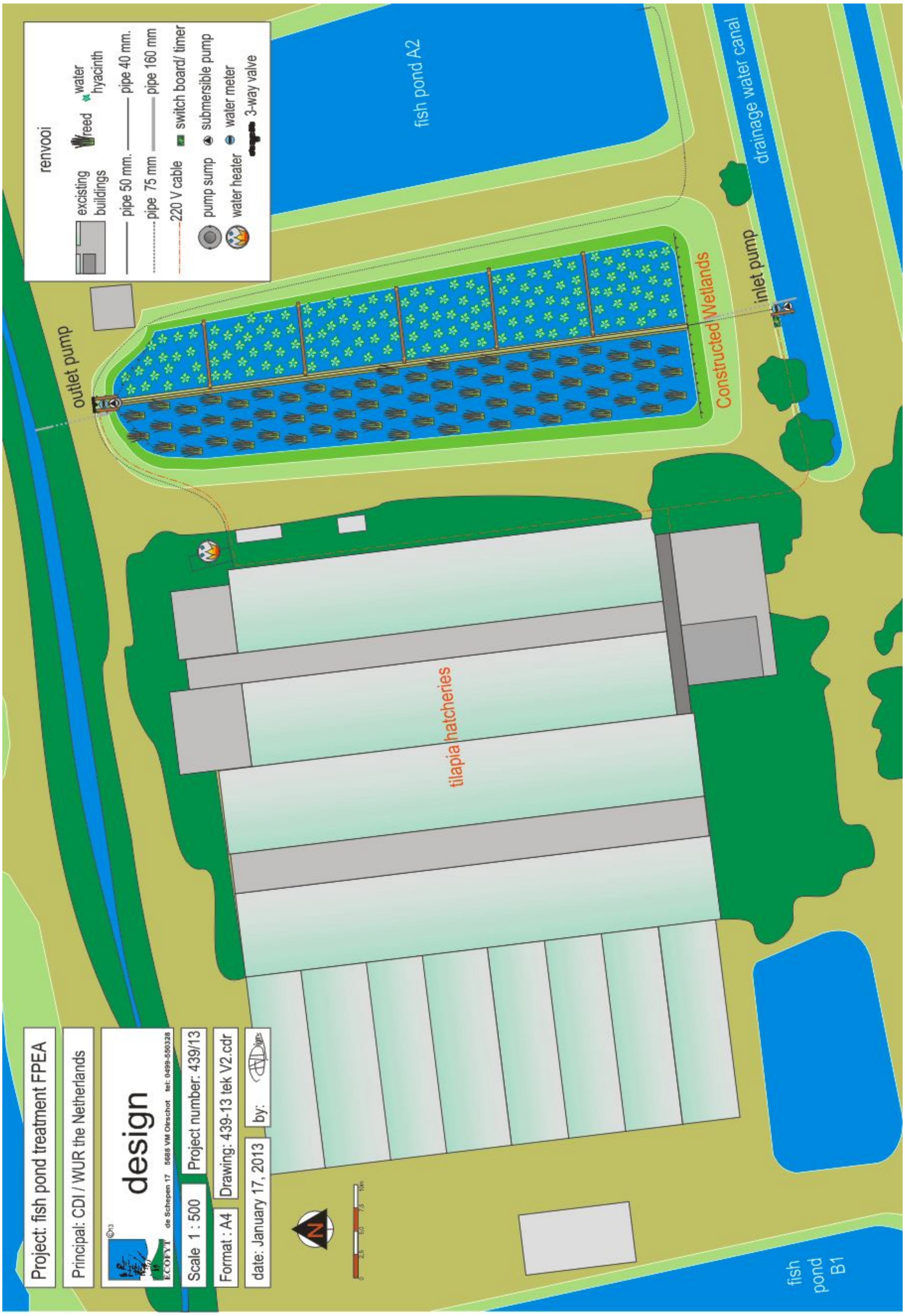
Appendix 1 Overview design of Pilot CW at fish farm 'Baledna', Kafr El Sheikh



Appendix 2 Considerations for successful construction and operation of a free water surface constructed (engineered) wetland.

Peter van der Heijden, Centre for Development Innovation, Wageningen UR
January 2013

The pilot Constructed Wetland (CW) that is proposed on Mr Diaa Awad El Beshbishi's farm is for testing the effectiveness of constructed wetlands, Surface Flow and Free Floating Macrophyte types, to treat drainage canal water with the objective to reduce the amount of compounds that are harmful for human health (especially heavy metals and pesticides). These two types of constructed wetland can treat more m^3 per m^2 wetland than sub-surface flow types, at lesser costs. The results of and experiences with this pilot are important for many fish farmers in Egypt. The Netherlands government is interested to assist with the design and construction of the CW (by means of financing expert advice and some equipment) on the condition that the results can be shared with other fish farmers. For the test to be reliable, Mr El Beshbishi will maintain good communication with Mr Frank van Dien and Mr Peter van der Heijden and do his best to provide the information that is requested.

It is understood that Mr El Beshbishi is interested in the filter to improve the quality of the water used in the hatchery and in his production ponds. Making a filter that only improves the water used in the hatchery does not match well with the purpose of the project, which is testing the suitability of CW as a technology to produce fish that is safer for people to eat (with less contaminants). If the proposed filter would only treat the water supply to the hatchery, the results are not relevant for consumption fish (The hatchery produces fry and fingerlings, not market-size fish). To match the aim of the project and the interest of Mr El Beshbishi, it is proposed to fill the production pond adjacent to the CW (pond A2) with water treated by the CW. Also additional water needed to maintain the water level in the adjacent pond (pond A2) will be water treated in the CW. When the production pond does not need water, the treated water can be used in the hatchery. To avoid contaminants stored in the pond bottom from entering the fish it is recommended to remove the sediment layer of the adjacent pond (pond A2).

- The treatment of the water in a constructed wetland is a process that has several major contributors for its success:
- Amount of dead plant material on the bottom. This material adsorbs heavy metals and pesticides. For this reason we propose rice straw to be 'planted' in the construction phase between the young reed plants. This will help to remove heavy metals in the first months of the filter, when the reed does not yet produce many dead leaves. Later, when the reed is bigger, sufficient dead plant material (dead leaves) will be produced by the reed plants.
- Bacteria that grow in the bottom, on the reed plants and roots of floating plants.
- Adsorption by plants (reed, water hyacinth, etc.) through the roots.

The higher the ratio between the volume of the filter basin and the amount of water that enters the filter basin to be treated, the better and more efficient the treatment will be. This ratio is called the hydraulic retention time. For example: a filter of 100 m^3 that receives and treats 25 m^3 of water/day has a hydraulic retention time (HRT) of 100 : 25 = 4 days. One could say that this means that the water stays on average 4 days in the filter. Higher HRT means that the filter basin has to be larger to treat a certain amount of water every day. For our designs we have used a HRT of 4, knowing from experiences of surface flow wetlands used near Lake Manzala and elsewhere that this gives often a good removal of polluting compounds. The water depth will be 30 cm on one side (with reed) and 35 cm on the other side (with water hyacinths). This means that for each m^3 of water to be treated a wetland surface area of ± 12 m^2 is needed. For pond A1 of Mr El Beshbishi's farm (approx. 865 m^2) this means that it can deliver **72 m^3 of treated water per day**.

During the testing of these wetlands we will try to determine the shortest Hydraulic Retention Time that will still eliminate the hazardous chemicals.

For our pilot it is important to have good control of the amount of water that is entering the filter every day. For this reason we recommend pumps with known characteristics, and a timing mechanism that controls the number of hours/day the pump is running. Submerged pumps use less electricity than electric dry land pumps. The submergible pump at the water inlet should be placed in a cage above the drainage canal bottom to avoid mud to be sucked in and to avoid that plants and rubbish can block the water from entering the pump.

For our pilot it is also important to know the exact amount of water that enters the filters every week or month. For this reason water volume meters are placed after every pump.

The wetland design is such that all water passes through the system while being in contact with as much organic material and plant material as possible.

Because an existing fish pond is used to make a constructed wetland, it is important to remove the layer of sediment (mud, sludge) at the bottom. In this layer of mud heavy metals and pesticides from the past years have accumulated, and these will enter the water and the fish again during the testing of the pilot CW. For this reason we strongly recommend to remove the top 10 cm of pond sediment. This mud can be used to restore roads or to elevate existing dikes.

Next, the bottom will be covered with a layer of 13 cm of clean sand on the west side and 8 cm of clean sand on the east side. This sand serves as 1) substrate in which reed shoots can easily grow roots, 2) as porous material for bacteria to settle and 3) as a clear cover of the clay to learn about deposits.

Heavy metals such as zinc and copper and also pesticide residues are removed from the water by attachment to organic materials (dead leaves, roots, etc.). In a newly built engineered wetland not much of such organic material can be found. For this reason we add a cheap source of organic material: rice straw. During the first year the straw will slowly decay but it will be replaced with organic material from the reed plants (dead leaves, etc.). We recommend to insert bundles of straw in the sand (between the reed shoots) to avoid that the straw starts floating and accumulating at the end of the filter or wherever the wind blows it.

It is proposed to use half of pond A1 as a Surface Flow constructed wetland, planted with reed and the other half as a Free Floating Macrophyte system in which not reed but water hyacinth is the main plant. Water hyacinth is commonly found in Khafr El Sheikh (and in the rest of Egypt) and absorbs great quantities of heavy metals and pesticides in its leaves and roots. The water depth in this part of the filter should be approx. 35 cm, to have more space for the roots. In this system all water will pass through the water hyacinth's roots and maximum treatment can be achieved. At the start of the project at least 1/3 of the surface should be covered with water hyacinths brought in from elsewhere, in the summer the remaining open space will be covered with this plant in only several weeks. Every month or every 6 weeks some water hyacinths can be removed from the basin, to stimulate the growth of (and absorption by) the remaining plants. For reason of comparison with the part of the pilot CW that is planted with reed also the bottom of this part of the filter will be covered with 8 cm of clean desert sand. We hope to compare the effectiveness of the surface flow reed filter with the surface flow water hyacinth filter.

Because it is important to involve the whole Constructed Wetland in the treatment and not only a part, the water will enter the constructed wetland via several inlet points distributed over the short side (south side) of the pond. In this way the water will travel through the wetland using the whole width of the pond. If the water would enter the constructed wetland via only one inlet point, most water might move in a straight line from the inlet to the outlet point, and the reeds or hyacinths at the side of the pond may not be involved in the filtering/treatment process. This would result in a less efficient treatment of the water.

To explore the potential of nature to improve the quality of life

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Report CDI-15-079

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