International Journal of GEOMATE, March, 2017, Vol. 12, Issue 31, pp. 45-50
Geotec., Const. Mat. & Env., ISSN:2186-2990, Japan, DOI: http://dx.doi.org/10.21660/2017.31.6532

USING FLOATING WETLAND TREATMENT SYSTEMS TO REDUCE STORMWATER POLLUTION FROM URBAN DEVELOPMENTS

Peter Schwammberger[1], Chris Walker[1, 2] and *Terry Lucke[1]

[1] Stormwater Research Group, University of the Sunshine Coast, Australia
[2]Covey Associates Pty Ltd, Sunshine Coast, Australia

*Corresponding Author, Received: 15 June 2016, Revised: 07 July 2016, Accepted: 23 Jan 2017

ABSTRACT: Floating treatment wetland (FTW) systems are an innovative stormwater treatment technology currently being trialled in Australia. FTWs provide support for selected plant species to remove pollutants from stormwater discharged into a storage basin. The plant roots provide large surface areas for biofilm growth, which serves to trap suspended particles and enable the biological uptake of nutrients. FTWs can be installed at the start of the construction phase and can therefore start treating construction runoff almost immediately. FTWs have the potential to provide a full range of stormwater runoff treatment (e.g. sediment and nutrient removal) from the construction phase onwards. A 101 m^2 FTWs has been installed within a greenfield development site on the Sunshine Coast, in Australia. The two-year research study investigated the pollution removal performance of the FTW for two different locations, one with low and one with moderate influent pollutant concentrations. This paper presents the research methodology used, and the initial study results of the treatment efficiency of FTWs.

Keywords: urban stormwater runoff, floating treatment wetlands, stormwater pollution, stormwater treatment

1. INTRODUCTION

Natural floating wetland ecosystems exist in many parts of the world, ranging from large floating marshes covering thousands of hectares in Louisiana [1] to smaller floating mires in the Netherlands [2]. Floating Treatment Wetlands (FTWs) are artificial systems that mimic the water treatment processes that take place in natural floating wetland islands [3]. FTWs are comprised of a floating structure planted with emergent macrophytes where the roots grow into the water column [4]. The roots provide a large surface area (Figure 1) for biofilm attachment. The biofilm adsorbs pollutants [5,6] while physically filtering and trapping suspended solids [7].

As FTWs are buoyant, they can be installed in most water bodies without significant earthworks, thereby offering stakeholders an effective, environmentally sustainable and cost-effective water treatment solution [8]. FTWs also offer terrestrial and aquatic habitats for wildlife which allows for greater ecological diversity [3].

Plant growth, establishment and survival in conventional stormwater treatment devices (e.g. constructed wetlands) are often affected by high flow velocities, the duration and depth of inundation, and the frequency of flooding or drought [9]. Consequently, the wetland area may need to be relatively large to buffer against these extreme water level fluctuations. Alternatively, the high flows may be designed to bypass the wetland all together resulting in a significant portion of stormwater runoff being untreated [10].

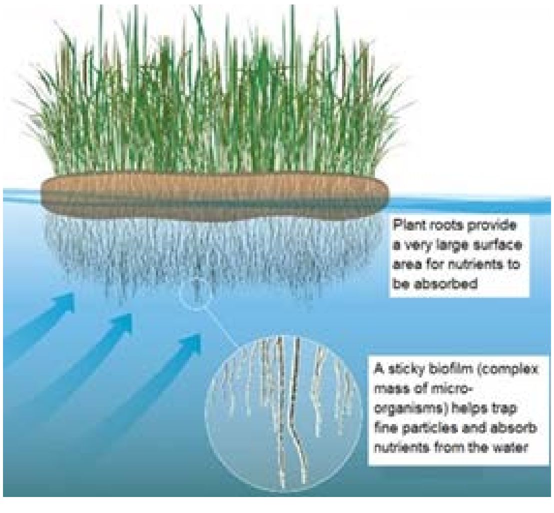

Fig. 1 Figure showing root hairs and vegetation above the floating mat [11].

The buoyancy of FTWs generally enables them to tolerate major fluctuations in water depth. This makes FTWs a reliable stormwater treatment device that protects plant health during extreme rainfall events. Furthermore, the extensive surface area of the root network can provide significantly greater pollution removal rates per unit area compared to constructed wetlands and other stormwater treatment systems.

Several mesocosm studies have been conducted to investigate the treatment efficiency of different plant species planted in FTWs. These studies have shown that FTW are effective at removing pollutants from both wastewater [12-15] and stormwater [7,16,17]. The number of field studies undertaken on FTWs is limited, particularly in the application of FTWs to stormwater treatment [3,18,19]. Smaller-scale field studies in the USA [19] and New Zealand [4] have shown FTWs to be effective in removing a variety of pollutants from stormwater runoff from highways.

To date, no previous studies have been undertaken in an urban residential setting, where there can be higher pollutant loads such as sediment, nutrients, and heavy metals. These urban stormwater pollutants can be readily transported to receiving waters due to an increase in impervious surfaces such as roads, sidewalks, driveways, parking lots and rooftops, as well as more efficient drainage pathways [6]. This paper describes the results of an ongoing field study conducted to assess the ability of FTWs to treat urban stormwater runoff from an existing urban development in Southeast Queensland (SEQ), in Australia.

2. MATERIALS AND METHODS

2.1 Study Site

This study was conducted in an existing lake within a development under construction on Bribie Island in Queensland, Australia. The entire development site has an area of 42.3 ha, with construction having commenced in 2014. At the start of the research project in September 2014, stormwater from a 10 ha existing residential catchment (external to the new development) discharged through two existing inlets into the study lake (Inlets 1 and 2 in Figure 2).

The study involved installing a new FTW in the existing lake shown in Figure 2. The FTW had a total area of 101 m^2 which was equivalent to approximately 0.1% of the development area. The FTW was comprised of 11 FTW modules, each of approximately 9 m^2 in area. The FTWs (www.spel.com.au) used in this study were composed of a 200 mm thick, recycled plastic fibre mat, injected with marine grade foam to provide buoyancy (Figure 3). Each mat had 40 pre-drilled holes to hold the plants. The holes were 100 mm in diameter and 150 mm deep. The mats were covered with coir matting and planted with tube stocks of *Carex appressa* at a density of two plants per hole (Figure 3).

To direct the stormwater inflow into the lake and through the FTWs to limit potential short-circuiting of the FTW (i.e. bypassing flows) experienced in other studies [10,18], impermeable polyvinyl chloride (PVC) curtains were installed along the sides of the FTWs that fanned out towards the lake banks (Figure 2). These ensured all inflows from Inlets 1 and 2 were treated by the FTWs.

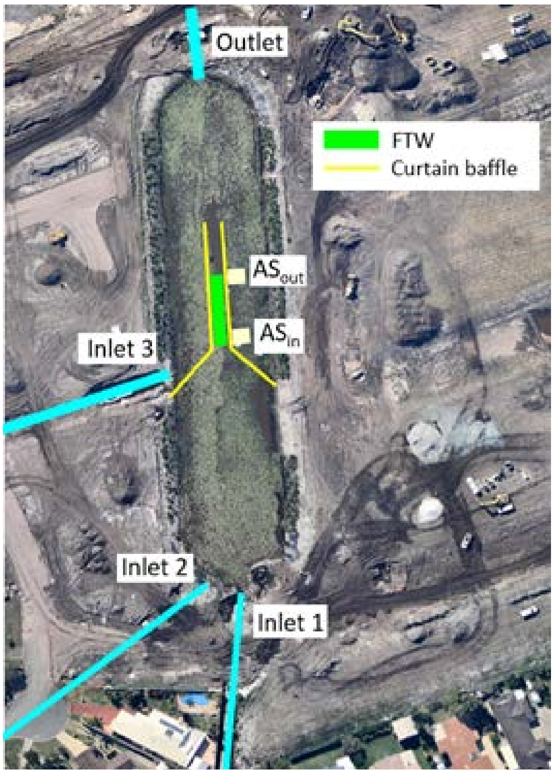

Fig 2 Initial location of the FTW and automatic samplers (AS$_{in}$ and AS$_{out}$).

Fig 3 Two of the FTW modules planted with *Carex appressa*.

Water quality analysis results from the first sampling period (from September to February 2015) showed that the influent pollutant concentrations were very low. In late February 2015, the study site was impacted by a tropical cyclone (Marcia - TCM) which caused some minor damage to the FTW. In particular, some of the anchoring cable supports were damaged which caused the FTW to shift its location. Portions of the PVC curtain were also damaged.

As the FTW needed realignment and repair after TCM, it was decided to use this opportunity to relocate the FTW, and to change the baffle configuration to enable the treatment of stormwater inflows from a different part of the catchment which was thought to have potentially higher pollution concentrations which were more in line with current, accepted ranges. This resulted in relocating the FTW to the new position shown in Figure 4.

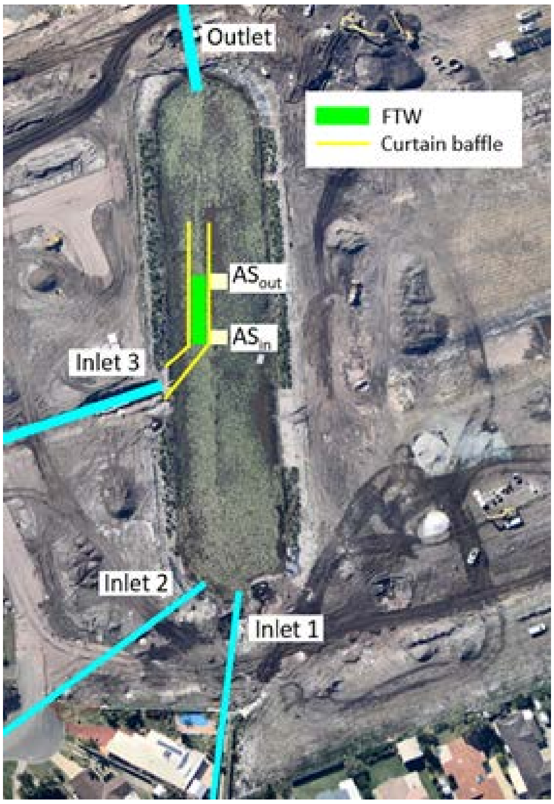

Fig 4 New location of the FTW and automatic samplers (AS_{in} and AS_{out}) after TCM

The new location meant the FTW received stormwater (Inlet 3) from a 5.3 ha existing residential area, as well as stormwater from a new 2.2 ha area of the Bribie Lakes development (Total treatment area = 7.5 ha). As the new 2.2 ha area was under construction, it was expected to have much higher influent pollutant concentrations. Prior to the reconfiguration of the FTW, the discharge from Inlet 3 bypassed the FTW.

2.2 Storm Event Sampling and Analysis

In order to standardize the sampling methods and procedures to capture qualifying storm events, a sampling protocol (Table 1) was developed [3] based on the protocol methods prescribed by the US EPA [20] and Auckland Regional Council [21].

Automatic water samplers (ISCO GLS - http://www.isco.com/) were installed upstream (AS_{in}) and downstream (AS_{out}) of the FTW (Figures

2 and 4) to collect water samples to be analysed for water quality parameters (Table 1) by a NATA (National Association of Testing Authorities) accredited laboratory. The samples were analysed for total suspended solids (TSS), total nitrogen (TN) and total phosphorus (TP) which are the three main stormwater pollutants of concern in Australia.

The auto-samplers were triggered by a combination of signals from a rain gauge and flow meter that were installed on site. The auto-samplers were programmed to collect 200 mL flow-weighted aliquots each time a cumulative volume of 15 kL registered at the flowmeter. This was equivalent to the runoff from a rainfall depth of 0.2 mm over the study catchment area. The 200 ml aliquots were composited into a nine litre bottle and sent to the laboratory for analysis.

Table 1 Sampling Protocol and Analysis Details

Parameter	Details
Min. rainfall depth	2mm in 30 min
Rainfall monitoring	Pluviometer
Min. storm duration	15 min
Min. dry period	antecedent 6 hours
Min. hydrograph	Sampling first 60%
Min. sample aliquots per storm event	8 inlet and 8 outlet subsamples
Sampling method	ISCO Auto-samplers, flow-weighted in 15 kL intervals
Sampler location	0.3 m upstream- and 0.3 m downstream of FTW
TSS & TDS	APHA (2005) 2540 C & D
TN & TKN	APHA (2005) 4500 N
Ammonia N	APHA (2005) 4500 NH3
NOx	APHA (2005) 4500 NO3
TP& Orthophosphate	APHA (2005) 4500 P
Particle size distribution (PSD)	Laser Diffraction

The water quality analysis results were used to estimate an Event Mean Concentration (EMC) for each storm event using Equation 1:

$$EMC = \frac{\sum_{i=1}^{n} V_i C_i}{\sum_{i=1}^{n} V_i} \quad (1)$$

where:
V_i = Volume of flow during period i;
C_i = Concentration associated with period i; and
n = total number of aliquots collected during event.

The water quality analysis results were also used to assess the overall system performance by calculating the pollution removal efficiency ratio (ER) using Equation 2:

$$ER = 1 - \frac{Mean\ EMC_{Out}}{Mean\ EMC_{In}} \qquad (2)$$

where:
EMC_{in} = Event Mean Concentration at AS1 and
EMC_{out} = Event Mean Concentration at AS2.

3. RESULTS AND DISCUSSION

Sampling commenced in September 2014 and continued through to February 2015 when the study site was affected by TCM. During this time, five qualifying storm events were captured. As shown in Table 2, results prior to TCM showed low concentrations of TSS, TN and TP. The concentrations ranged from 4 to 10 mg/L for TSS, from 0.41 to 0.91 mg/L for TN, and from 0.005 to 0.078 mg/L for TP. These concentrations were well below the ‘typical’ Australian average urban pollutant loads expected in SEQ which are 151 mg/L for TSS, 1.82 mg/L for TN and 0.34 mg/L for TP [22].

Table 2 Pollution removal efficiency prior to TCM

Parameter	TSS (mg/L)		TN (mg/L)		TP (mg/L)	
Date	In	out	In	out	In	out
07/09/14	10	14	0.51	0.53	0.005	0.005
23/09/14	5	4	0.41	0.44	0.005	0.005
25/09/14	4	4	0.41	0.43	0.005	0.005
07/11/14	10	2	0.65	0.56	0.052	0.038
20/11/14	8	15	0.97	0.52	0.078	0.032
Mean Conc.	7.4	7.8	0.59	0.49	0.029	0.017
Efficiency Ratio	-5%		16%		41%	

For events prior to TCM, the average pollutant removal efficiency ratios (ER) for TSS, TN and TP were -5%, 16% and 41%, respectively (Table 2).

These were below the minimum pollutant removal ERs recommended for urban developments in SEQ of 80%, 60% and 45%, for TSS, TN and TP, respectively [23]. The variation in the results between the individual storm events was substantial and pollution removal ER ranged from between -88% and 80% for TSS, -6% and 47% for TN and between 0% and 59% for TP. However, these results needs to be considered carefully, and within the correct context.

For, example, the 41% ER results for TP removal (Table 2) needs to be considered with care as there was no net removal of TP for three of the five events as the samples were below detection limits. The high variability of the results was a result of the low pollutant concentrations generated from the existing residential development.

Furthermore, it was considered that the 70 m length of open water in the lake in front of the FTW was acting as a type of pre-treatment system for the inflowing stormwater leading to sedimentation, and portions of TSS and particle bound pollutants not reaching the FTW. The site is also very sandy which could also reduce runoff volumes and result in low pollution loads.

Once the location of the FTW was changed after TCM to treat the stormwater from Inlet 3 (Figure 4) water quality sampling results show much higher inlet pollution concentrations (Table 3), which were more in line with current expectations.

The inlet pollutant concentrations ranged from 11 to 414 mg/L for TSS, from 0.6 to 3.2 mg/L for TN and from 0.03 to 0.28 mg/L for TP. These results are more in-line with the expected pollutant concentration ranges for stormwater runoff from urban developments in SEQ. [22].

Table 3 Pollution removal efficiency post-TCM

Parameter	TSS (mg/L)		TN (mg/L)		TP (mg/L)	
Date	In	out	In	out	In	out
28/09/15	323	51	1.00	0.25	0.280	0.1
23/10/15	11	4	0.70	0.30	0.030	0.02
07/11/15	414	24	3.20	0.70	0.280	0.03
15/11/15	26	16	1.10	0.70	0.050	0.05
29/11/15	270	28	2.20	1.30	0.140	0.02
30/01/16	50	26	1.10	2.20	0.040	0.04
01/02/16	19	36	0.80	1.60	0.040	0.07
06/02/16	19	24	0.60	0.80	0.050	0.03
13/02/16	37	19	1.40	2.10	0.060	0.04
06/03/16	56	15	1.20	1.10	0.100	0.11
Mean Conc.	122.5	24.3	1.33	0.11	0.107	0.05
Efficiency Ratio	80%		17%		52%	

The average pollutant removal efficiency ratios for TSS, TN and TP were 80%, 17% and 52%, respectively. Compared to the initial setup where TSS concentrations often increased when passing through the FTW, the results after TCM show much better TSS removal for higher influent concentrations, as well as for higher flow rates (Table 3).

It is difficult to accurately assess the efficiency of treatment systems when pollution concentrations are close to detection limits, as even a small change in concentration yields a significant change in the average results. The relocation of the FTW after TCM, and the subsequent increase in pollutant loading, resulted in a higher pollutant removal ratio for all pollutants monitored in the study.

The FTW showed a high variability in treatment performance for stormwater runoff with very low pollutant concentrations. However, when the pollutant loads were closer to those typically expected for stormwater in SEQ, the ER was substantially higher. The results of this study demonstrate that the sampling location, and the influent pollutant loads are extremely important. The study showed that these variables can significantly influence the results of performance and efficacy measurements of FTW systems.

To further investigate the stormwater treatment performance of FTWs, a new four-year research study has recently commenced in a new development site on the Sunshine Coast in Queensland, Australia. The new study will be conducted on a 2,100 m^2 FTW treating stormwater runoff from a new 42 ha residential development which is dominated by a clayey substrate. The stormwater runoff water quality will be characterised and assessed during both the construction and the operational phases of the development. The ability of FTWs to improve stormwater quality, and to manage urban lake health will be evaluated throughout the four-year study which will complement the results of the Bribie Island study.

The study results will be of significant interest for the developers and local government authorities and could potentially influence stormwater management practices, both in Australia, and internationally.

4. CONCLUSION

This study initially investigated the pollutant removal performance of a FTW receiving stormwater runoff from a 10 ha residential site. However, stormwater pollutant concentrations from the site were found to be far below typical concentrations for urban stormwater runoff in Australia and this resulted in low pollutant removal performance results for the FTW.

After approximately six months, the FTW was moved to a new location (catchment area = 7.5 ha) with higher influent pollutant concentrations that were more in-line with typically expected values for urban catchments in Australia. The pollutant removal performance of the FTW in the new location increased significantly and the average pollutant removal efficiency ratios were found to be 80%, 17% and 52%, respectively for TSS, TN and TP. These results were much closer to the recommended removal rates in Australia.

The study results demonstrate that sampling location, and influent pollutant loads are extremely important and that these variables can significantly influence the results of performance and efficacy measurements of FTW systems.

The study has demonstrated that FTW are a viable option for urban stormwater treatment that have numerous advantages compared to traditional systems. These include reduced land requirements, resilience to extreme water depth and volume changes, as well as potentially enhancing habitat, recreational, and aesthetic values within the urban landscape. It is anticipated that the study results could significantly influence the stormwater management in Australia, and the rest of the world.

5. REFERENCES

[1] Sasser CE, Gosselink JG, Shaffer GP, “Distribution of nitrogen and phosphorus in a Louisiana freshwater floating marsh”, Aquatic Botany, Vol. 41, 1991, pp. 317–331.

[2] van Diggelen R, Molenaar WJ, Kooijman AM, “Vegetation succession in a floating mire in relation to management and hydrology”, J. of Vegetation Science, Vol. 7, 1996, pp. 809–820.

[3] Walker C, Nichols P, Reeves K, Lucke T, Nielson M, Sullivan D, “Using Floating Wetlands to Treat Stormwater Runoff from Urban Catchments in Australia”, in Proc. 13th International Conf. on Urban Drainage, Malaysia, 2014.

[4] Borne KE, “Floating treatment wetland influences on the fate and removal performance of phosphorus in stormwater retention ponds”, Ecolog. Engineering, Vol. 69, 2014, pp. 76-82.

[5] Headley TR, Tanner CC, “Constructed Wetlands with Floating Emergent Macrophytes: An Innovative Stormwater Treatment Technology”, Critical Reviews in Environmental Science and Technology Vol. 42, 2012, pp. 2261–2310.

[6] Lynch J, Fox LJ, Owen JS, Sample DJ, “Evaluation of commercial floating treatment wetland technologies for nutrient remediation of stormwater”, Ecolog. Engineering, Vol. 75, 2015, pp. 61–69.

[7] Headley TR, Tanner CC, “Floating wetlands for stormwater treatment: Removal of copper, zinc and fine particulates”, Auckland Regional Council Technical Report, 2008.

[8] Hartshorn N, Marimon Z, Xuan Z, Cormier J, Chang NB, Wanielista MP, “Complex interactions among nutrients, chlorophyll-a, and microcystins in three stormwater wet detention basins with floating treatment wetlands”, Chemosphere, Vol. 144, 2016, pp. 408–419.

[9] Chang NB, Islam MK, Wanielista MP, “Floating wetland mesocosm assessment of nutrient removal to reduce ecotoxicity in stormwater ponds”, Int. J. Environ. Sci. Technol. Vol. 9, 2012, pp. 453–462.

[10] Headley TR, Tanner CC, "Application of floating wetlands for enhanced stormwater treatment: A review", NIWA Client Report, Auckland Regional Council, 2006.
[11] Royal Botanic Gardens Melbourne (RBGM), "Plant Collections, Lake System Wetlands", website, accessed on 15-5-2016 at: https://www.rbg.vic.gov.au/visit-melbourne/attractions/plant-collections/lake-system-wetlands
[12] Ash R, Truong P, "The use of Vetiver grass wetlands for sewerage treatment in Australia", 3rd International Conference on Vetiver, 2003.
[13] Ayaz SC, Saygin O, "Hydroponic tertiary treatment", Water Research, Vol. 5, 1996, pp. 1295–1298.
[14] Kyambadde J, Kansiime F, Dalhammar G, "Nitrogen and phosphorus removal in substrate-free pilot constructed wetlands with horizontal surface flow in Uganda" Water, Air, and Soil Pollution, Vol. 165, 2005, pp. 37–59.
[15] van de Moortel AMK, Meers E, De Pauw N, Tack FMG, "Effects of vegetation, season and temperature on the removal of pollutants in experimental floating treatment wetlands", Water, Air and Soil Pollution, Vol. 212, 2010, pp. 281–297.
[16] Kerr-Upal M, Seasons M, Mulamoottil G, "Retrofitting a stormwater management facility with a wetland component" Journal of Environmental Science and Health, Vol. 35, 2000, pp. 1289–1307.
[17] Revitt DM, Shutes RBE, Llewellyn NR, Worrall P, "Experimental reedbed systems for the treatment of airport runoff", Water Science and Technology, Vol. 36, 1997, pp. 385–390.
[18] Borne KE, Fassman-Beck EA, Winston RJ, Hunt WF, Tanner CC, "Implementation and Maintenance of Floating Treatment Wetlands for Urban Stormwater Management", J. Environ. Eng. Vol. 141, 2015, pp. 4015030.
[19] Winston RJ, Hunt WF, Kennedy SG, Merriman LS, Chandler J, Brown D, "Evaluation of floating treatment wetlands as retrofits to existing stormwater retention ponds", Ecological Engineering, Vol. 54, 2013, pp. 254–265.
[20] Strecker E, Urbonas B, Quigley M, Howell J, Hesse T, "Urban Stormwater BMP Performance Monitoring", United States Environmental Protection Agency, 2009.
[21] Wong G, Ansen J, Fassman E, "GD03 Proprietary Devices Evaluation Protocol (PDEP) for Stormwater Quality Treatment Devices", New Zealand, Auckland Council, 2012.
[22] EDAW/ AECOM, "Urban stormwater- Queensland best practice environmental management guidelines", Australia, Environmental Protection Agency, 2009.
[23] Queensland Government, "State Planning Policy 2014", The State of Queensland, Department of State Development, Infrastructure and Planning, 2014, website, accessed on 17-10-2016 at: http://www.dilgp.qld.gov.au/resources/policy/state-planning/state-planning-policy-jul-2014.pdf
[24] Knight RL, Clarke RA, Bastian RK, "Surface flow treatment wetlands as a habitat for wildlife and humans", Water Science and Technology, Vol. 44, 2001, pp. 27–37.
[25] Lee JS, Li MH, "The impact of detention basin design on residential property value: case studies using GIS in the hedonic price modelling", Lands. & Urban Planning, Vol. 89, 2009, pp. 7–16.
[26] Rousseau DPL, Lesage E, Story A, Vanrolleghem PA, De Pauw N, "Constructed wetlands for water reclamation", Desalination, Vol. 218, 2008, pp. 181–189.