Effect of wetaland plant root development on hydraulic conductivity in horizontal flow constructed wetland system.

H S Shashibhushana[1,2], Basappa Lokeshappa[2], Malhotra Nishchay[1]

[1] Bharat Electronics Limited, Environmental Engineering Department
[2] University BDT College of Engineering, Department of Civil Engineering
H S Shashibhushana, shashi78bel@gmail.com, +91-9448346599

Abstract

Reduction of hydraulic conductivity over period of operation of Constructed wetland due to clogging of subsurface media is a common phenomenon which affects the overall expected performance of wetland treatment systems. In order to determine the effect of root development in subsurface media on hydraulic conductivity, planted and unplanted (Control) constructed wetland test bed were subjected to in-situ test wherein Vettiver (Vetiveria Zizanioide) was used as wetland plant in 20 mm size single gravel as subsurface media. In order to simulate root development in operation of constructed wetland,Vettiver (Vetiveria Zizanioide) was planted in separate test bed and root development over the period of 150 days were studied. Hydruaclic conducitivity of test bed was estimated using Darcy's formual. Hydraulic conducitivity reduced from 398.77 m d^{-1} to 354.29 m d^{-1} and from 394.82 m d^{-1} to 328.66 m d^{-1} over a period of 5 months respectively in unplanted and planted wetland system. Results indicated that hydraulic conductivity reduced in planted wetland sytem compared to unplanted but reduction is not statistically significant.

Key word: Horizontal flow constructed wetland (HFCW), Hydraulic conductivity, Rootzone

1. Introduction

Constructed wetland (CW) is a choice now days since it is treated as green and sustainable technology. CW was considered as technology requiring less energy, lesser machinery, lesser cost, less green house gas emission and low skilled supervision but for larger area requirement compared other methods of treatment[1] [2]. CW has high sustainability potential when properly designed, operated and maintained[3].

Despite of advantages of CW they offers, CW also poses operational problem of clogging of media which in turn affects desired performance and expected life of CW[4]. Ponding, short circuiting are the consequences of media clogging. Over a period performance of CW reduces, media getting choked due to sedimentation, biofilm growth, root development and biomass accumulations [5]. Media and the characteristics of the wastewater contribute to clogging of rootzone [6].

Clogging of Wetland media due to plant roots and rhizomes is observed differently by researchers in different ways. A few research reported that plant roots promote conductivity or suspension of support material [7] [8] and a few research reported that root presence as the reason for clogging and surface flow[9][10].

Subsurface media is one among major component of CW provides holdfast for microbial growth and plants in addition to maintaining hydraulic conductivity. Gravel is the commonly used subsurface media in CW[11][12]. Other materials such as husk, slag and bark are also used as subsurface media [13]. Pollutant removal is influenced by the characteristics of media especially mineral composition of the media which involve in certain oxidation and reduction reaction in pollutant stabilization process[14][15].

Hydraulic conductivity will have bearing on long term performance of CW. Hydraulic conductivity determines the hydraulic retention time in the CW. The main parameter influencing the hydraulic conductivity is the grain size distribution[16]. CW with fine soil based substrates though provide best filtration and sedimentation but also poses disadvantage of low hydraulic conductivity. Contrary to fine size, coarse-sand and gravel based media provides higher conductivity at the cost of moderate filtration.

In-situ methods of measurement practiced largely to determine the extent and impact of clogging in porous media were: (1) hydraulic conductivity measurements to indicate the severity of clogging, (2) tracer testing to understand the effect of clog matter on flow through the porous medium (3) characterization of the clog matter to explain the degree and nature of clogging[17][18].

In Subsurface flow CW, media is saturated and hence saturated hydraulic conductivity (Ks) is used as indicator to deterring hydraulic conductivity of rootzone of CW[19][20]. Ks vary with the operating time of a treatment unit. Porous space obstruction of CW modifies the hydrodynamic conditions, notably with respect to Ks. As the occlusion of interstitial spaces progress results in decrease in Ks and consequently, surface flow occurrence which ultimately affects treatment efficiency of CW[21]. This mechanism makes the hydraulic conductivity a variable parameter having strong relation with porous medium clogging during operation period. Change of subsurface media pore geometry and effective pore radii over a period of time contributes to the clogging of rootzone[5].

However, determination of K_s especially in subsurface flow CW is difficult since media undergoes the influence of out of control factors such as surface flow and short circuits, in addition to porosity reduction because of growth biofilm, penetration of roots and accumulation solid residues in CW.

Studies on clogging process in Horizontal subsurface flow constructed wetland (HFCW) have only been widely reported in the scientific literature in recent years[22][21]. In a way to state that Ks in situ measurements are still developing technologies due to process dynamics of CW. Research studies infers that Ks measurement in CW are imperative since the monitoring of hydrodynamic conditions of these systems is essential for their operational improvement without compromising treatment efficiency.

Objective of this study aimed at (a) determining the effect of wetland plant on hydraulic conductivity Ks in planted and unplanted horizontal flow constructed wetland system for treating domestic sewage (b) inferring on root zone development in constructed wetland through rootzone development study.

2. Materials and Methods

2.1. Site description

Study was conducted in Bharat Electronic primise of Jalahalli, Bengaluru Karnataka state, India. It is located at 12.9716°N latitude and 77.5946°E longitude and has an average altitude of 900 meters (3,000ft.) above sea level.

2.2. Horizontal flow constructed wetland system

Two sets of HFCW, one with Vetiver (HFCW-P) as emergent macrophyte plant and another without plant as a control (HFCW-C) of 1.8 M long, 0.8 M wide and 0.7 M deep were constructed in 25 cm thick brick massoanary. Water tightness was ensured by appropriate plastering with leak proof admixture. Distribution wall was constucted at 0.3 meter distance keeping opening at the bottom to ensure that the wastewater passed through the root zone. The CW was filled with gravels of 20 mm size. Outlet was kept 5 cm below the inlet level to maintain hydraulic gradient of 2.7%. Porosity of media as per insitu test found to be 0.385 for gravel size of 20mm. Wastewater (Sewage) generated in BEL campus collected in tank of 300 litre and released through valve to the wetland on daily basis according to the set HRT. Typical schematic setup is shown in Figure 1.

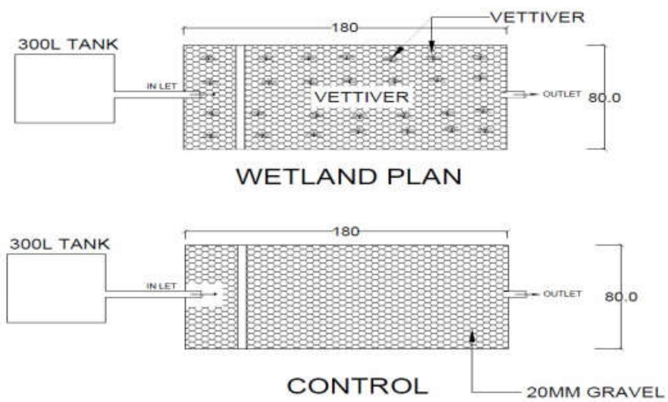

Figure 1. Typical schematic setup

2.3. Growing of Wetland Plants

Vetiveria Zizanioides saplings in bundle of five were planted in a 20 mm size gravel media with soil (5% by v/v) to protect the root initially. *Vetiveria Zizanioides* (Vetiver) saplings were planted at a spacing of 15 cm from each other in a row and six rows of 30cm each other.

2.4. Root development Simulation Setup

Vetiver in a bundle of five were planted in 10 trays of dimension 300mm X150 mmX150mm in 20 mm size gravel media with soil (5% by v/v) to support root growth and to mainting same condtions as made for Horizontal flow constructed wetland system including day of sampling and feed water.

2.5. Measurements

2.5.1. Root growth: The root growth is measured in terms of volume, length and number of primary roots. Volume of root growth was treated as reduction in the pore volumes of the media in root zone in turn considered as reduction of porosity of the system.

Destructive sampling was done to determine the root growth every month. Plant which was grown in the tray to simulate growth of plant in wetland was removed from tray. Jelly entrapped in the roots was removerd, washed and dried. Roots were placed in a measuring beaker of 500 ml and water was filled to the 500 ml mark. Difference in the 500 ml and water requied to reach 500ml treated as root volume. Root lenght and numbers are counted manually. Root growth was measured once in month over period of 5 months.

2.6. Hydrulic conductivity

Hydrulic conductivity of operational bed and control was measured using Darcy's Law of constant head method in a saturated contidion.

Darcy's Law equation is as follows[17][23]

$$Q = Kf\, I\, AC \tag{1}$$

Where
A_C(m^2) is the cross sectional area of the bed,
Q (m^3/ d) is average flow
K_f (m/ s) is hydraulic conductivity
I= dH / dS (m/m) is the hydrualic gradient in the bed.

Rearraning equation :

$$Kf = Q\, L / A_C\, (h1 - h2) \tag{2}$$

Where
L is the distance between inlet and outlet point in the axial flow direction(m)
h_1 is the water depth at the inlet point(m)
h_2 is water depth at the downstream point(m)

In order to determine hydrulic conductivity co-efficient, insitu test method was formulated by maintaing constant head. Head was maintained by providing excess discharge point towards inlet side of CW at 50 mm above the treated water discharge point. Hydrualic gradient (H/L) govering the flow was 50/1800. Disharge (Q) from wetland outlet over a period of time (t) was collected and measured for flow rate (V/t) using volumetric equation. Hydrulic conductivity was measured once in month over period of 5 months.

Wetland and controls both were subjected to raw sewage flow of 120 LPD and 180 LPD during experimental study in order to evalute removal efficiency from November 2018 to February 2018.

2.7. Data analysis

Data analysis was perfomed using MINITAB 14, statistical software (Minitab, Inc,14.12.0.0 Version).

3. Results and Discussion

Hydrualic conductivity (K_s) of HFCW-P and HFCW-C was determined using Darcy's equation based on constant head method. In order to determine effect of wetland plant on hydraulic conductivity (K_s), comparision was made between HFCW-P and HFCW-C. Further to asertain the effect of root growth wetland plants was removed from the tray and root development in term volume, lenght and numbers were measured(Table 1). Volume of root growth (Vr) was treated as reduction in the pore volumes of the wetland rootzone in turn conisdered as reduction in pore volume

Table1. Details of Hydrulic conductivity of test beds

Sl. No	Day	HFCW-C(m. d^{-1})	HFCW-P (m. d^{-1}	Volumeof roots (ml)	No of primary roots	Length(cm)
1	0	398.77	394.82	15.0	2.0	25.0
2	33	387.99	381.80	67.5	36.0	35.0
3	61	376.20	359.97	85.0	56.0	39.0
4	89	365.10	345.42	105.0	88.0	37.5
5	120	354.29	328.66	140.0	109.0	42.0

Hydraulic conductivity of HFCW-C found to be varied from 398.77 m d^{-1} to 354.29 m d^{-1} over a period of 5 months. Similarly for the HFCW-P were found to be varied from 394.82 m d^{-1} to 328.66 m d^{-1}(Fig 2). Two sample t test between planted and unplanted wetland inffers difference is not statistical significant($p>0.05$).

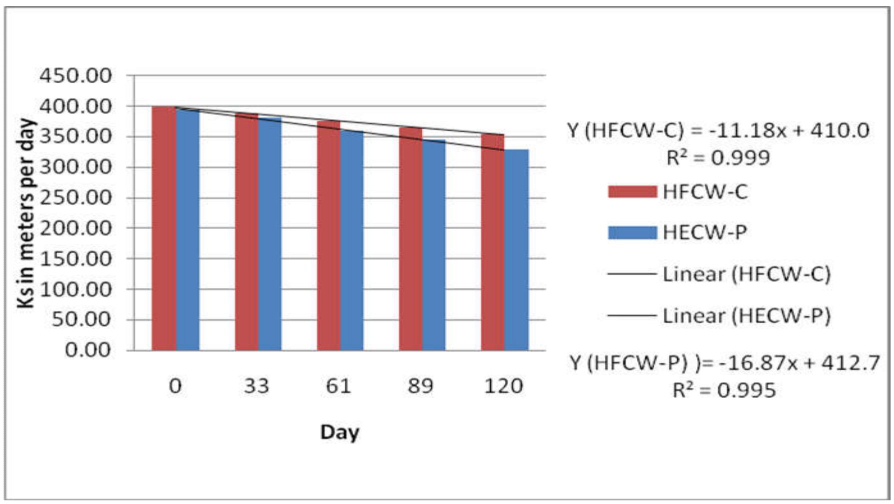

Figure 2. Hydrualic Conductivity of CW

Root growth measured in terms of volume, numbers and lenght increase from 15 ml to 140 ml per plant, 2 numbers to 140 numbers and 25 cm to 42 cm m over a period of five months.Growth pattern is given in Fig 3, 4 & 5.

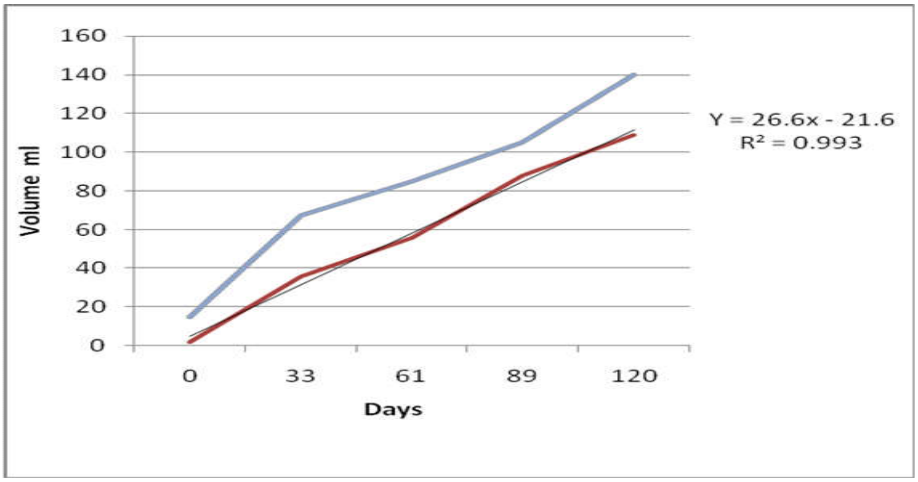

Figure 3. Volume of Root growth

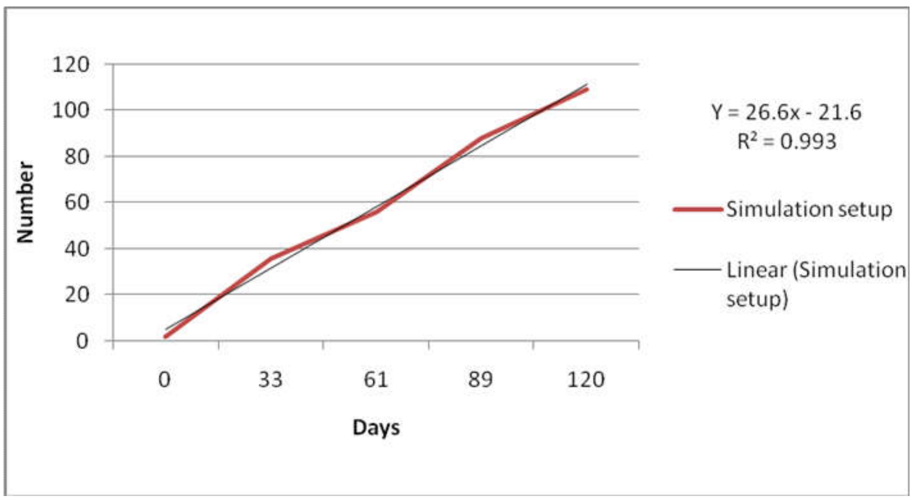

Figure 4. Number of Root growth

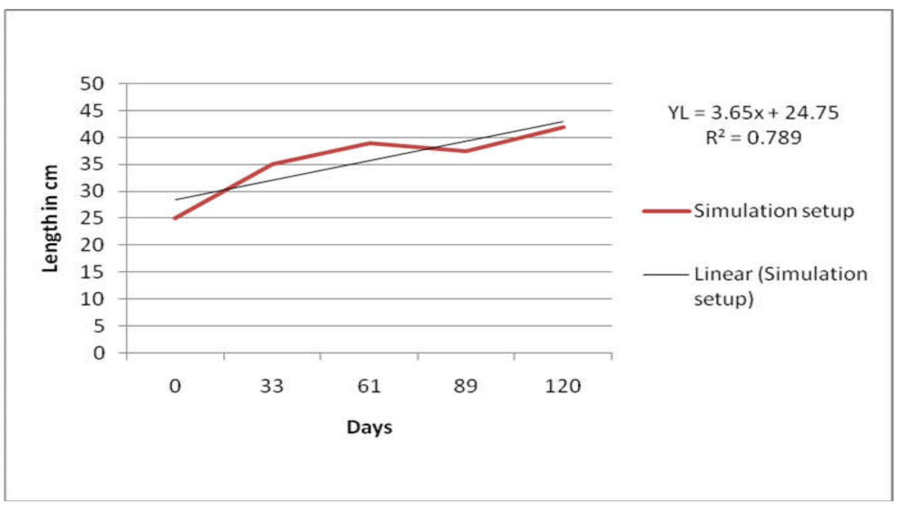

Figure 5. Length of Root growth

It is found that K_s value obtained during experiment indicates that there was reduction in the hydrualic conductivity in HFCW-P and HFCW-C. However K_s reduction in HFCW-P is more compared to HFCW-C. It is inffered that though reduction in the K_s was noted during the study but reduction is not statistically significant($p>0.375$) as indicated by Student Two sample t test (2t Test). In the present experiment root penetration was observed from 15 cm to 42 cm deep in the tray over a period of five months. It is also assumed the same level of root penetration was occurred in the constructed wetland system. Even though root growth observed up to 42cm over a period of five months. It was observed that reduction of pore volume due to roots over conductivity reduction in not propotional to reduction of conductivity in the absence of root. Graphic representation shows that ratio of conductivity over reduction pore volume is between HFCW-P and control HFCW-C is not same and having different slope(HFCW-P : 0.045 and HFCW-C: 0.033) and inview of the it is considered that hydrualic conductivity reduction is not related. However difference in slope is not very high. All the more volume of root occupied is only of 2.5% of the total pore volume of constructed wetland. Maximum root volume occupying was reported to be 5 % only reported by[24]. The results obtained in the present experiments depict the same trend obtained by[25]. However K_s value varies due to variation in inflow characteristics also. Reason attributed for reduction in conductivity in subsurface media are accumulation of organic matter in the sewage and growth of mircoorgnism biofilm, synthesis of material from organic mater degradation and litters exhuded from plants roots. As the media in the subsurface flow constructed wetland is always saturated and the cumulative biological, chemical and physical treatment processes that take place in constructed wetland which results in gradual clogging of the porous media[26][27].[28] reported that organic loading also contributes for premautured clogging in addition to suspended solids. The growth of the biological film, accumulation of sludge, plant roots and deposition of chemical precipitation decreases the amount and volume of the void spaces over the time thus reducing the hydraulic conductivity of the rootzone media[25][21]. It is felt by many authors that effect of plant root growth in subsurface is debatable and many author felt that root growth increase conductivity[9][8] while some author opine that root growth reduce conductivity by reducing the pore size of subsurface media[25]. As reported by[3]multiple factors such as the applied TSS load, cultivated plant species, system operating time, wastewater characteristics, climatic conditions, etc. contributes to overall reduction in conductivity. As reported by[19], plants can maintain hydraulic conductivity over time by means of creation of preferential paths for water flow as a result of root growth and particularly, rhizome penetration in the bed. It was also reported by same author that formation of annular holes, even cracks, at plant root and around tuber n the bed due to stem and leaf movement resulting from wind force. But reduction in conductivity due to root growth was observed in the present study.

Reduction in hydraulic conductivity is due to roots and solid accumulation which were not found directly related. Similar observation was made by [29].Hydraulic efficiency of constructed wetland was determined by various factors such as aspect, bottom topography, water depth, vegetation, obstructions, and inlet/outlet position all influence wetland hydrodynamics[30].

Trend analysis obtined for conductivity of planted system(Ksp) over rootvolume(Vr) indicates decling trend with best fit of cubic equation with high R Sq of 99.5%(R sq adj 98%) with a equation as follows:

$$Ksp=378.4+1.536Vr-0.03058Vr^{2} + 0.000122Vr^{3}$$

4. Conclusions:

Hydraulic conductivity reduction over a period of time is normal phenomena in the CW systems. Reduction in Hydraulic conductivity was noted in planted as well as unplanted wetland system. However reduction in hydraulic conductivity observed to be slightly more in the planted wetland compared to unplanted system but reduction is not significant even though pore size reduction occurs through root penetration. Progressive reduction of hydraulic conductivity in the CW system due to root growth was not very significant at the cost of other benefits such as rootzone aeration, plant uptake and conductive atmosphere facilitated by wetland plant. Findings of the above experiment provide important insights for the future development of finding progressive hydraulic conductivity through clogging mechanism caused by root penetration and accumulation of degradation organic matter in constructed wetland.

Acknowledgement

The Author expresses his gratitude to Bharat Electronic Ltd and staff of Environmental Engineering department for providing the facility and continuous support.

References

1. Calheiros, C.S.C., Rangel, A.O.S.S., Castro, P.M.L. (2007), Constructed wetland systems vegetated with different plants applied to the treatment of tannery wastewater. Water Research, (41): 1790-1798.
2. Vymazal J , Kropfelova L (2009) Removal of organics in constructed wetlands with horizontal sub-surface flow: A review of the field experience . Science of the total environment. 407: 3911 – 3922.
3. De la Varga, D., Díaz, M. A., Ruiz, I., & Soto, M. (2013). Avoiding clogging in constructed wetlands by using anaerobic digesters as pre-treatment. Ecological Engineering, 52, 262–269. doi:10.1016/j.ecoleng.2012.11.005.
4. Pedescoll, A., Sidrach-Cardona, R., Sánchez, J. C., Carretero, J., Garfi, M., & Bécares, E. (2013). Design configurations affecting flow pattern and solids accumulation in horizontal free water and subsurface flow constructed wetlands. Water Research, 47(3), 1448–1458. doi:10.1016/j.watres.2012.12.010.
5. Brovelli, A., Malaguerra, F., & Barry, D. A. (2009). Bioclogging in porous media: Model development and sensitivity to initial conditions. Environmental Modelling & Software, 24(5), 611–626. doi:10.1016/j.envsoft.2008.10.001.
6. Albuquerque, A., Oliveira, J., Semitela, S., Amaral, L., 2009. Influence of bed media characteristics on ammonia and nitrate removal in shallow horizontal subsurface flow constructed wetlands. Bioresour. Technol. 100, 6269–6277.
7. Vymazal J (2011) Plants used in constructed wetlands with horizontal subsurface flow: a review Hydrobiologia. 674:133–156 Published online: 17 May 2011.
8. Oren Shelef, Amit Gross, Shimon Rachmilevitch (2013) Role of Plants in a Constructed Wetland: Current and New Perspectives Water 2013, 5, 405-419; doi:10.3390/w5020405.
9. Fu, G., Zhang, J., Chen, W., & Chen, Z. (2013). Medium clogging and the dynamics of organic matter accumulation in constructed wetlands. Ecological Engineering, 60, 393–398. doi:10.1016/j.ecoleng.2013.09.012 .
10. Pozo-Morales, L., Franco, M., Garvi, D., & Lebrato, J. (2013). Influence of the stone organization to avoid clogging in horizontal subsurface-flow treatment wetlands. Ecological Engineering, 54, 136–144. doi:10.1016/j.ecoleng.2013.01.008.
11. W. E., Sanford, Steenhuis, T. S., Parlange, J.-Y., Surface, J. M., & Peverly, J. H. (1995). Hydraulic conductivity of gravel and sand as substrates in rock-reed filters. Ecological Engineering, 4(4), 321–336. doi:10.1016/0925-8574(95)00004-3.

12. Wu, S., Kuschk, P., Brix, H., Vymazal, J., & Dong, R. (2014). Development of constructed wetlands in performance intensifications for wastewater treatment: A nitrogen and organic matter targeted review. Water Research, 57, 40–55. doi:10.1016/j.watres.2014.03.020.

13. Seo, D.C., Cho, J.S., Lee, H.J., Heo, J.S.,(2005). Phosphorus retention capacity of filter media for estimating the longevity of constructed wetland. Water Res. 39,2445–2457. https://doi.org/10.1016/j.watres.2005.04.032.

14. Vymazal J (2005), Horizontal sub-surface flow and hybrid constructed wetlands systems for wastewater treatment. Ecological Engineering, 25(5), 478-490.

15. U. Stottmeister, A. Wiebner, P. Kuschk, U. Kappelmeyer, M. Kastner, O. Bederski, R.A. Muller, H. Moormann (2003) Effects of plants and microorganisms in constructed wetlands for wastewater treatment. Biotechnology Advances. 22:93– 117. doi:10.1016/j.biotechadv.2003.08.010.

16. Nivala, J., Knowles, P., Dotro, G., García, J., & Wallace, S. (2012). Clogging in subsurface-flow treatment wetlands: Measurement, modeling and management. Water Research, 46(6), 1625–1640. doi:10.1016/j.watres.2011.12.051.

17. Pedescoll, A., Knowles, P. R., Davies, P., García, J., & Puigagut, J. (2011). A Comparison of In Situ Constant and Falling Head Permeameter Tests to Assess the Distribution of Clogging Within Horizontal Subsurface Flow Constructed Wetlands. Water, Air, & Soil Pollution, 223(5), 2263–2275. doi:10.1007/s11270-011-1021-4.

18. Pedescoll, A., Sidrach-Cardona, R., Sánchez, J. C., Carretero, J., Garfi, M., & Bécares, E. (2013). Design configurations affecting flow pattern and solids accumulation in horizontal free water and subsurface flow constructed wetlands. Water Research, 47(3), 1448–1458. doi:10.1016/j.watres.2012.12.010.

19. T J Chang, Chang, Y.-S., Lee, W.-T., & Shih, S.-S. (2016). Flow uniformity and hydraulic efficiency improvement of deep-water constructed wetlands. Ecological Engineering, 92, 28–36. doi:10.1016/j.ecoleng.2016.03.028.

20. Knowles, P. R., Griffin, P., & Davies, P. A. (2010). Complementary methods to investigate the development of clogging within a horizontal sub-surface flow tertiary treatment wetland. Water Research, 44(1), 320–330. doi:10.1016/j.watres.2009.09.028.

21. Cota, R.S,Von Sperling, M., Penido, R.C.S. Tracer studies and hydraulic behaviour of planted and un-planted vertical-flow constructed wetlands. Water Science and Technology, Oxford, v.64, n.5, p. 1056-1063, 2011.

22. Knowles, P., Dotro, G., Nivala, J., & García, J. (2011). Clogging in subsurface-flow treatment wetlands: Occurrence and contributing factors. Ecological Engineering, 37(2), 99–112. doi:10.1016/j.ecoleng.2010.08.005.

23. Edwards, G. S. (1992). Root distribution of soft-stem bulrush (Scirpus validus) in a constructed wetland. Ecological Engineering, 1(3), 239–243. doi:10.1016/0925-8574(92)90005-m.

24. Baptestini, G. C. F., Matos, A. T., Martinez, M. A., Borges, A. C., & Matos, M. P. (2017). Hydraulic conductivity variability in horizontal subsurface flow constructed wetlands. Engenharia Agrícola, 37(2), 333–342. doi:10.1590/1809-4430-eng.agric.v37n2p333-342/2017.

25. Pozo-Morales, L., Franco, M., Garvi, D., & Lebrato, J. (2013). Influence of the stone organization to avoid clogging in horizontal subsurface-flow treatment wetlands. Ecological Engineering, 54, 136–144. doi:10.1016/j.ecoleng.2013.01.008.

26. Nivala, J., & Rousseau, D. P. L. (2009). Reversing clogging in subsurface-flow constructed wetlands by hydrogen peroxide treatment: two case studies. Water Science and Technology, 59(10), 2037–2046. doi:10.2166/wst.2009.115.

27. Carballeira, T., Ruiz, I., & Soto, M. (2017). Aerobic and anaerobic biodegradability of accumulated solids in horizontal subsurface flow constructed wetlands. International Biodeterioration & Biodegradation, 119, 396–404. doi:10.1016/j.ibiod.2016.10.048

28. Caselles-Osorio, A., Puigagut, J., Segú, E., Vaello, N., Granés, F., García, D., & García, J. (2007). Solids accumulation in six full-scale subsurface flow constructed wetlands. Water Research, 41(6), 1388–1398. doi:10.1016/j.watres.2006.12.019.

29. Suliman, F., Futsaether, C., & Oxaal, U. (2007). Hydraulic performance of horizontal subsurface flow constructed wetlands for different strategies of filling the filter medium into the filter basin. Ecological Engineering, 29(1), 45–55. doi:10.1016/j.ecoleng.2006.07.017.

30. Albuquerque, A., Oliveira, J., Semitela, S., & Amaral, L. (2010). Evaluation of the effectiveness of horizontal subsurface flow constructed wetlands for different media. Journal of Environmental Sciences, 22(6), 820–825. doi:10.1016/s1001-0742(09)60183-2.