Mansoura Engineering Journal

Volume 35 | Issue 1 Article 20

12-1-2020

# Effect of Loading Rates in Free Water Surface Constructed Wetlands for Treating Polluted Water, Case Study: Bahr El-Baqar Drain.

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# EFFECT OF LOADING RATES IN FREE WATER SURFACE CONSTRUCTED WETLANDS FOR TREATING POLLUTED WATER, CASE STUDY : BAHR EL-BAQAR DRAIN.

# تأثير معدل التحميل في الأراضي المبتلة على معالجة المياه الملوثة، حالة دراسية: مصر بحر البقر

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**الخلاصة:** تصريف مياه الصرف الصحي والصناعي المعالجة جزئيا او غير المعالجة تسبب تلوث مياه المصارف. ولمعالجتها هذه المياه تم التفكير في وسيلة غير مكلفة وسهلة التشغيل والصيانة مثل المعالجة باستخدام الأراضي المبتلة. وفي هذا البحث تم استخدام معدلات مختلفة في طريقة الأراضي المبتلة ذات السطح المياه المكشوف لمعالجة المياه الملوثة في مصرف بحر البقر الذي يستقبل الكثير من مياه الصرف الصحي بالإضافة إلى مياه الصرف الزراعي. ويتكون النظام المستخدم من ثلاث مجموعات رئيسية وهي كما يلي: المجموعة الأولى خمس أحواض متتالية ذات معدل سريان عالي مقداره 0.344 م$^3$/ م$^2$ في اليوم ، المجموعة الثانية خمس أحواض متتالية ذات معدل سريان منخفض مقداره 0.048 م$^3$/ م$^2$ في اليوم ، المجموعة الثالثة حوض عام ذو تصرف مقداره 500 م$^3$/ اليوم، بتصرف إجمالي مقداره 25000 م$^3$/ اليوم للمجموعات الثلاثة. وقد تبين من التجارب والقياسات التي تمت ان تركيزات الملوثات في المياه كانت منخفضة نسبيا لزيادة نسبة مياه الصرف الزراعي بالمياه. كما اظهرت النتائج ايضا انه لا يوجد فرق كبير في كفائة المعالجة بين الأنواع الثلاثة، وأن الأحواض المتتالية ذات معدل السريان العالي مرضية. وكانت كفائة معالجة الملوثات المختلفة كما يلي: **$BOD_5$ (52%), COD (50%), TSS (87%), TDS (32%), $NH_4$-N (66%), $PO_4$ (52%), Fe (51%), Cu (36%), Zn (47%) and Pb (52%).** وكانت تركيزات المواد المختلفة بعد المعالجة متوافقة مع النسب المسموح بها في القانون.

## Abstract

Disposing partially treated or untreated domestic and industrial wastewater into Egyptian drains violates their water quality standards and makes drains water unsuitable for reuse and pollute the receiving water body. A growing interest in effective low-cost treatment of polluted water and wastewater has brought many researches on constructed wetlands (CWs). Many CWs have been commissioned to treat various types of waters such as urban, agricultural runoff, municipal, industrial wastewaters, and acid mine drainage. This study evaluate a free water surface (FWS) CWs -(by far the largest application CWs in Egypt)- used to enhance water quality in Bahr El Baqar drain which located on the northeastern edge of the Egyptian Nile Delta, and discharge its water to Lake Manzala which has many fishing activities and connect to the Mediterranean Sea. The full capacity of the system is 25000 m$^3$/d, the amount of water is divided to three parts; five

Accepted March 31, 2010.

FWS CWs beds of high flow rate "HFR" of 0.344 $m^3/m^2$-d, five FWS CWs beds of low flow rate "LFR" of 0.048 $m^3/m^2$-d and reciprocated cells of flow 500 $m^3$/d. The concentrations of different contaminants along the CWs system were measured and analyzed for an assessment and modeling of treatment efficiency. The effluent was compared with the Egyptian regulation of water quality in agricultural drains (Law 4/1994). Due to the high percent of agriculture drains, the concentrations of contaminants in the influent were relatively low, thus the percentages of removal for the different contaminants were as follows: $BOD_5$ (52%), COD (50%), TSS (87%), TDS (32%), $NH_4$-N (66%), $PO_4$ (52%), Fe (51%), Cu (36%), Zn (47%) and Pb (52%). The natural vegetation also increased the value of dissolved oxygen in the treated effluent considerably. There was little difference in the removal efficiencies between the HFR and LFR beds in the system.

**Key words**

Polluted drain water, constructed wetlands, free water surface, hydraulic loading rates, nutrient removals, trace metals.

## 1. INTRODUCTION

The Egyptian drains receives huge quantity of partially treated or untreated domestic and industrial wastewater, which in turn ends up discharging in canals, lakes, or seas, violates their water quality standards and makes drain water unsuitable for reuse and pollute the receiving water body. Wastewater effluents from household and industries tend to be polluted by biodegradable organic matter. Therefore, the discharge of such waste into watercourses causes a serious deterioration and consumes a large amount of oxygen present in the water body. The amount of waste discharged to receiving water bodies far exceeds the natural ability of these bodies to attenuate the pollutants. The current quality of drainage water restricts the availability of this resource for usage. Drainage water quality in Egypt, especially in the lower zone of the Delta, suffers from numerous types of pollution. This represents a health hazard and threatens the lives of farmers and other people eating the infected crops [1].

Simple treatment methods such as: wetlands have been developed, particularly over the last two decades, capable of reducing the treatment cost and the complexity of operation without scarifying the degree of pollution control. These methods are reliable and appropriate to the local conditions, and demands only limited financial resources. A growing interest in effective low-cost treatment of polluted water and wastewater has brought about research on constructed wetlands (CWs). In CWs, treatment performances were accomplished through an integrated combination of biological, physical, and chemical interactions among wetland components [2], [3], [4]. As a sustainable method for wastewater treatment, many CWs had been commissioned to treat various types of waters such as urban, agricultural runoff, municipal, industrial wastewaters, and acid mine drainage [5], [6], [7], [8], [9], [10].

CWs can be divided into two types namely; Free water surface (FWS) System; and Subsurface Flow (SSF) System. Free water surface (FWS) or Surface Flow (SF) system is divided into three types: emergent macrophyte based, free floating macrophyte based and submerged macrophyte based. FWS system typically consists of parallel basins or channels with a relatively impermeable bottom soil or subsurface barrier, emergent vegetation, and shallow water depth of 0.1 to 0.6 m. With sufficient wetland area, FWS constructed wetlands had used to meet discharge standards of less than 10 mg/l biological oxygen demand (BOD), total suspended solid (TSS), and total nitrogen (TN) on a monthly average basis in many examples of FWS in the United States [5].

Low number of pilot and large scale applications of CWs is under operation in Egypt. Examples of these limited applications can be viewed in (i) Lake Manzala Engineered Wetland, that is a large scale application providing FWS system to treat approximately 25,000 $m^3/d$ (by far the largest application in Egypt), (ii) Abou Attwa pilot hydroponics basins where SSF are constructed; (iii) other smaller applications are scattered in limited different regions in Egypt mainly SSF type.

This paper is evaluating and modeling a FWS CWs used to enhance water quality in Bahr El Baqar drain which located near Lake Manzala on the northeastern edge of the Nile Delta, Egypt. The drain discharge its water to Lake Manzala which has many fishing activities and connect to the Mediterranean Sea. The drain subjects to pollution loads as a result of discharges from areas lacking treatment facilities. Such discharge may thus be a mix of domestic, industrial and agriculture discharges with the later representing the larger amount of discharge (often over 90% of discharge) providing dilution of other contaminants discharged in to water streams.

## 2. MATERIALS AND METHODS

The current study was carried out to investigate and modulate the use of CWs system to improve water quality from the polluted Bahr El Baqar drain where Lake Manzala Engineered Wetland was constructed to investigate the use of FWS system (both at low rate and high rate of flow) to provide adequate treatment and enhance water quality. The CW at Lake Manzala is a large pilot scale in Egypt using principally FWS system for providing adequate treatment/polishing to enhance the water quality (from Bahr El Baqar Drain). The system consists of three lifting pumps from the drain, two sedimentation basins of capacity 25000 $m^3$, two drying beds of surface area 2000 $m^2$ for drying sludge, ten FWS CWs beds (planted with *Phragmites Australis* and *Typha* -cattails) running at different flow rates, channels and pipes to distribute and collect water of the system. Figure 1 shows the schematic plan and flow line diagram of different element of Lake Manzala CWs.

The performance of the CWs used in the agricultural industry often depends on their shape, size, design and hydraulic loading rates for a specific type of wastewater [9], [10], [11].

The full capacity of the facility understudy is 25000 $m^3$/day with dividing the amount of water to three parts; five FWS beds of flow 21500 $m^3$/day (high flow rate "HFR" of 0.344 $m^3/m^2$-d), five FWS beds of flow 3000 $m^3$/day (low flow rate "LFR" of 0.048 $m^3/m^2$-d) and reciprocated cells of flow 500 $m^3$/day. Each bed is 50 m width and 250 m length (divided into five cells of dimension 50m *50m) with an average depth of 0.40 m as to allow proper growth of the plants. The effluent of the three types of treatment goes back to the collecting channel then directed to Bahr El Baqar drain or the reuse area.

The current study is concerned with 4 beds of the ten (two for LFR beds and two for LFR beds). Flow rates corresponding to low and high hydraulic loadings were 0.048 and 0.344 $m^3/m^2$-d (m/d) respectively. The concentrations of different contaminants along the beds were measured and analyzed for an assessment of treatment efficiency during 2005-2008. The effluent was compared with the Egyptian regulation of water quality in agricultural drains (Law 4/1994). Different parameters were measured along the basins/beds to assess the removal efficiency of different contaminants among which are; Temperature (°C), Hydrogen Ion Concentration (pH), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Biological (Biochemical) Oxygen Demand ($BOD_5$), Chemical Oxygen Demand (COD), Ammonium Nitrogen ($NH_4$-N), Nitrate Nitrogen ($NO_3$-N), Phosphorus ($PO_4^{3-}$), Trace

Metals (Fe, Cu, Zn, Pb and Cd), and Fecal Coliform (FC). Table 1 provides information on the raw wastewater quality in Bahr El Baqar drain (the source of wastewater used during the experimental work on the full scale CW).

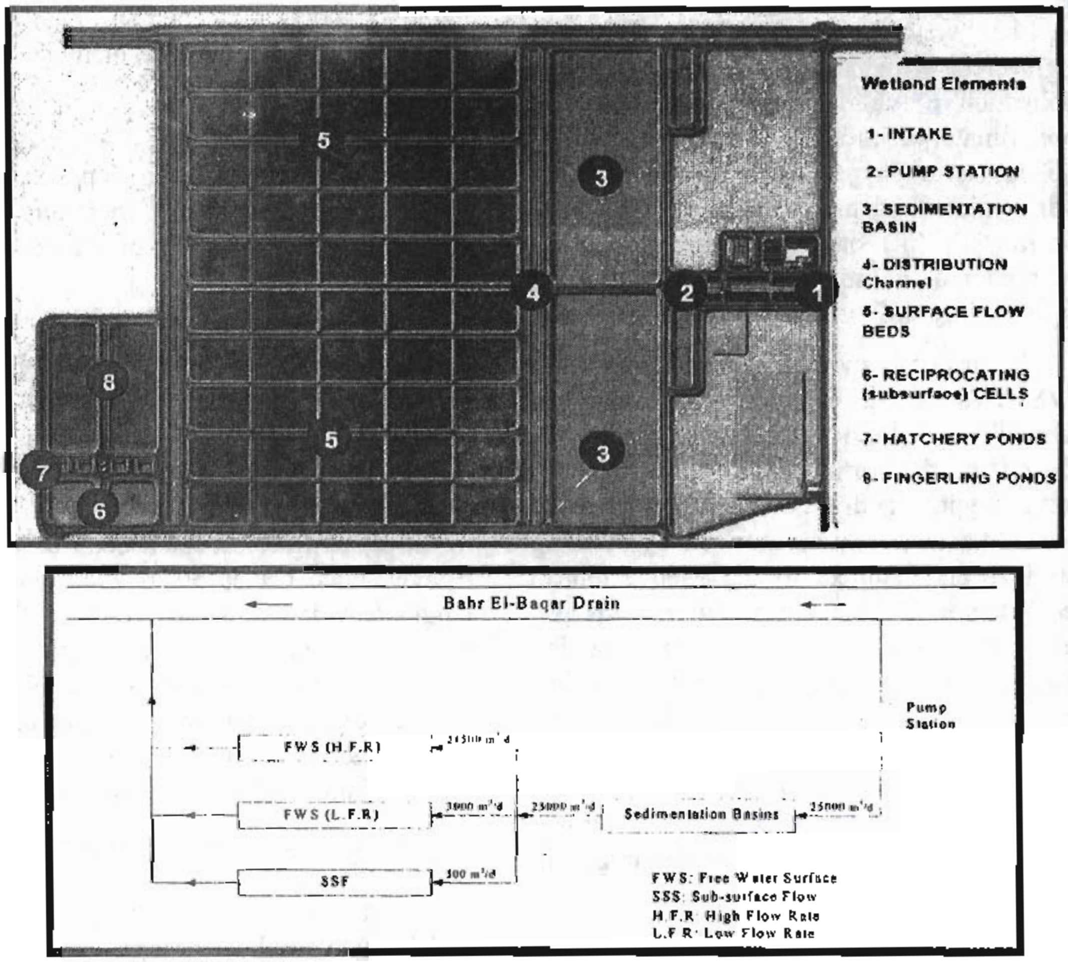


Figure 1. Schematic plan and flow line diagram of Lake Manzala CW.

*Table 1 Characteristics of water quality in Bahr El-Baqar drain.*

| Parameter | Unit | Bahr El-Baqar Drain | Required Level Law 4/1994 |
|---|---|---|---|
| COD | mg/l | 72 - 122 | 80 |
| $BOD_5$ | mg/l | 28 -100 | 40 |
| TSS | mg/l | 50 -130 | 50 |
| DO | mg/l | 1.0 -2.10 | 4.0 |
| $NH_4$-N | mg/l | 1.80 -4.50 | 3.0 |
| $PO_4^{3-}$ | mg/l | 0.80 -2.30 | 1.0 |
| pH | Value | 7.3 – 7.6 | 6 - 9 |

## 3. RESULTS AND DISCUSSIONS

The treatment mechanisms and processes within CWs are highly complex, and include microbial, biological, physical and chemical processes that may occur sequentially or simultaneously [5], [7], [8] [12]. The hydraulic loading rates applied to CWs have varied from 0.024 to 0.3570 $m^3/m^2$-d "m/d" [2]. The CWs utilize wetland plants, soils, and associated microorganisms to remove contaminants from wastewater. They are generally reliable systems with no anthropogenic energy sources or chemical requirements, a minimum of operational requirements, and large land requirements.

The full scale pilot treatment plant under investigation uses CWs of FWS to treat the polluted water from Bahr El Baqar drain through a series of channels planted with the common reed ***phragmites australis*** at variable flow rates; 4300 $m^3$/d for the HFR bed and 600 $m^3$/d for the LFR bed, under continuous operating period of 24 hours a day. The treatment efficiency of the FWS was assessed by monitoring various parameters that reflect the treatment performance as noted above.

There was no significant differences between water temperature of influent and effluent, it has been suggested that this may have beneficial effects on plant growth by providing a more stable environment. The temperature variations were recorded during the four seasons. Temperature of the inlet flow ranged between 26.2 °C - 34.5 °C during summer months and 17 °C - 26.8 °C during winter months. However, little changes in temperature between inlet and outlet points were observed with mean values 28.5 °C and 22.5 °C in the outlet point during summer and winter respectively. The pH values of the inlet flow were fluctuating during the study period. In summer values between 7.3 – 8.6 were recorded, while in winter the recorded values ranged from 7.65 – 8.12. In general, pH showed little decrease at end of the bed, where recorded mean values of 7.9 and 7.8 at the inlet and outlet points.

Dissolved Oxygen (DO) concentrations were hardly detected in the inlet effluent during summer sampling (0.7 – 0.9 mg/l). On the other hand, values detected during winter ranged from 0.8 to 1.3 mg/l. The system showed good efficiency to raise the DO concentration of the treated effluent, confirmed by the highly significant difference between inlet and outlet levels of DO. The mean values of DO in the outlet effluent were 7.2 mg/l during summer and 8.1 mg/l during winter. Figure 2 shows mean inlet and outlet levels of DO during both seasons and along the bed length.

The highest values of DO were found during low temperature for the beds while the lowest value of DO was found during high temperature. DO concentrations increase through bed length being highest at the effluent side (7.60 mg/l) for the rapid flow rate regime, while it has 8.20 mg/l at the end of low flow. DO can range from zero to more than twice the theoretical solubility in response to many ecosystem variables. Wetlands surface water typically have a vertical gradient in DO, with high DO at the air water interface and very low DO at the sediment-water interface [13]. The DO concentration in the HFR beds was slightly higher than that found in the LFR beds; especially at the end with percentage of about 11%.

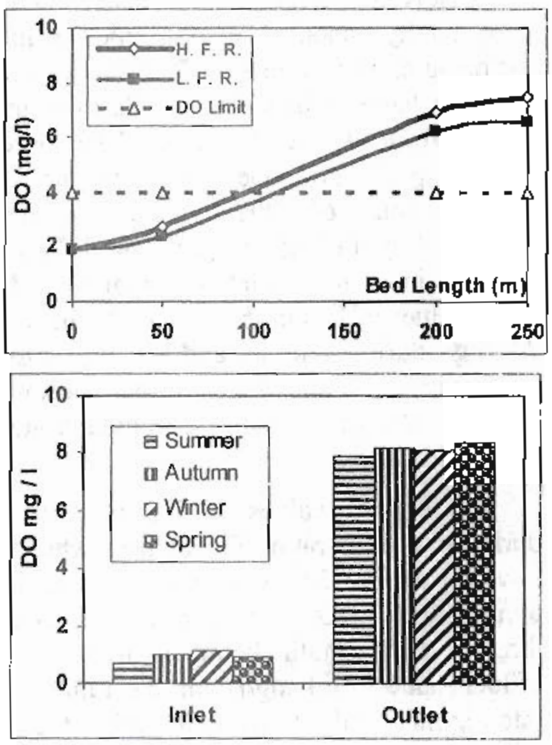


**Figure 2.** Variation of DO values along the bed length and in inlet and outlet water

In surface flow the major oxygen source for these reactions is re-aeration at the water surface as well as from the roots of the plants. Low efficiency at low input concentration appears to be related to the internal production of $BOD_5$ in surface flow CWs. Wetlands support a large and diverse population of bacteria which grow on the submerged roots and stems of aquatic plants and are of particular importance in the removal of $BOD_5$. Scholz, et al. [14] and Mustafa, et al. [15] reported that the CW systems had a high capacity to remove pollutants due to the large size of the wetland cells and the relative high mean retention time. Figure 3 indicates the good efficiency of the system to reduce the $BOD_5$ values during the months of the study. Levels of $BOD_5$ varied from 50.0 to 65 mg/l in the inlet wastewater. Reductions to the range of 20.5 – 30.0 mg/l were achieved during summer, while those achieved during winter were in the range of 22 – 36 mg/l.

Statistical analysis showed highly significant difference between inlet and outlet levels of $BOD_5$. Seasonal variations in performance concerning nutrient removal were observed. The $BOD_5$ concentrations within the inflow were relatively low in summer and fall compared to winter and spring. The natural self-purification decreases the pollution in the Bahr El Baqar drain. Figure 3 indicates the decrease of inlet levels of $BOD_5$ during summer and winter. The concentration of $BOD_5$ were the lowest at the end of the treatment beds of HFR with about 47% removal efficiency while at the end of the LFR beds indicated a removal efficiency of approx. 53.0%.

There was a general trend between increased BOD loading and increased effluent concentration. The average $BOD_5$ loading of HFR and LFR bed was about 138 and 28 kg $BOD_5$/ha-day respectively. The figure reveals slightly effluent variation for both BOD loading and shows slightly variation in effluent quality at the lower BOD loading rates for different seasons. The seven times of increasing hydraulic and BOD loadings resulted in only about 6 % of removal efficiency increase. These could be because of the low inlet $BOD_5$ of the influent water which might indicate that the high flow rate (and corresponding high BOD loading rates in range of 125 - 135 kg/ha-day) could be safely used to treat the low organic polluted water (about 40 mg/l) for effluent of 20 mg/l.

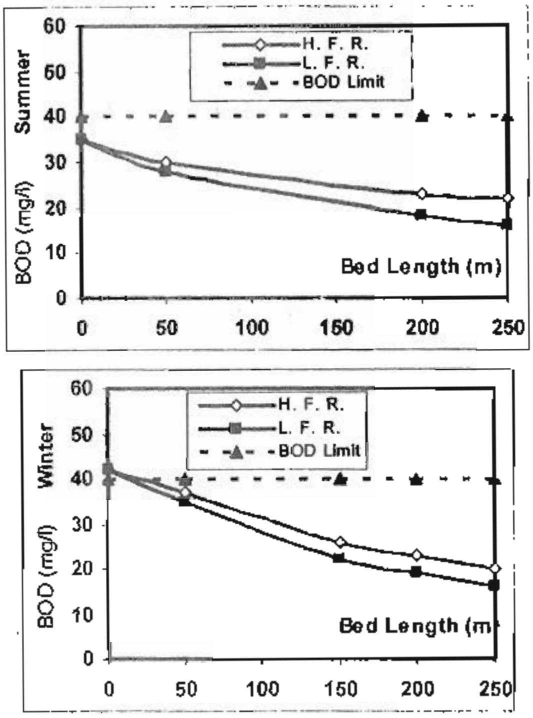


**Figure 3.** Variation of BOD5 along the bed length in summer and Winter.

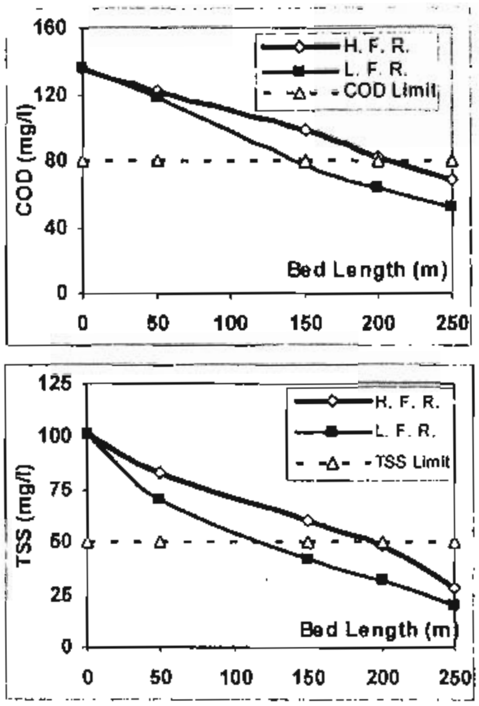


**Figure 4.** Variation of COD and TSS concentration along the bed length.

The results of COD and TSS for both inflows water and effluent from the FWS CWs are shown in Figure 4 illustrating the effect of bed length and different type of flow rates on COD and TSS. The mean of inlet concentration of COD in wastewater entering the beds was about 140.0 mg/l. The concentration of COD was the lowest at the end of the HFR beds with about 46.0 % removal efficiency, while it has a removal efficiency of COD at the end of the LFR of about 52.0%. BOD:COD ratio in the inlet polluted water was calculated in order to assess the nature of the treated effluent during the study period. Domestic wastewater has a ratio of more than 0.4, while the industrial toxic waste is usually lower than this ratio and recalcitrant wastes can approach zero [16]. The results showed large variations of COD:BOB ratio ranged from 0.2 to 0.8, indicating the mixed industrial and domestic origin of the effluent.

Total Suspended Solids (TSS) showed different patterns during the period of the study. The TSS values of the influent ranged from 90 to 130 mg/l throughout the study. In summer, the mean TSS values of the influent was 110 mg/l, while some increase was observed in autumn. The open water areas as wetland encourage the algal growth and increase the effluent TSS. To help minimize the potential for algal growth, the hydraulic retention time was designed for less than 2 to 3 days in each LFR cell (and more less in the HFR cells), where the growth cycle of algae is approximately 7 days [5]. Figure 4 showed the lowest TSS at the end of the LFR beds with about 89 % removal, while the removal efficiency of TSS at the end of the HFR beds of approx. 82%. The figure reveals slightly effluent variations for both HFR and LFR beds and shows slightly variation in COD and TSS for different seasons. The seven times of increase hydraulic loading resulted in only about 7 % of COD and TSS removal efficiency increase. These could indicate that the HFR could be sufficient to reduce the low

COD and TSS polluted water to the allowable limits.

Low water velocities in the HFR and LFR beds, coupled with the presence of vegetation promotes fallout and filtration of solid materials. The quiescent water conditions of a wetland are conducive to the sedimentation of wastewater solids. The transfer of suspended solids from the polluted water to the sediment bed in the FWS has important consequences both for the quality of the water and properties and function of wetland [13]. The particulate matters increased in the first reed bed followed by a decrease with distance along the beds. Scholz et al. [14] suggested that removal of sediment will be required approximately every 10 years from the first cell, and between 20 and 60 years from subsequent cells.

The discharge of nitrogen for receiving water is of concern for a number of reasons. Excessive accumulation of nitrogen in surface waters can lead to ecological imbalances that may cause over-growth of plants and animals, leading to water quality degradation (eutrophication). Ammonia nitrogen may deplete DO in natural waters by way of microbial nitrification reactions. High concentration of the unionized ammonia species are toxic to fish and other aquatic life. Nitrate and nitrite nitrogen constitute a public health concern, primarily related to methemoglobinemia and carcinogenesis. The important inorganic forms of nitrogen in wetlands are ammonia-nitrogen ($NH_4^+$-N), nitrate-nitrogen ($NO_3^-$-N) and nitrite-nitrogen ($NO_2^-$-N) [8].

Mean inlet and outlet levels of $NH_4^+$-N and $NO_3^-$-N in the study area are shown in Figure 5. The mean of inlet concentrations of $NH_4^+$ in wastewater entering the beds was about 9.0 mg/l and were the lowest at the end of the LFR beds with about 63 % removal, while the removal efficiency at the end of HFR beds of approx. 62%. The CWs have manifold processes of nitrogen removal and retention that include ammonia volatilization, nitrification, denitrification, nitrogen fixation, plant and microbial uptake, ammonification, nitrate-ammonification, anaerobic ammonia oxidation, ammonia adsorption and burial [9]. The removal occur by bacteria present in polluted water and aeration in beds then, additional oxidation occur by oxygen pumped plants and by increasing of surface area for bacteria attachment that lead to oxidation. $NH_4^+$-N removal increased from spring to summer.

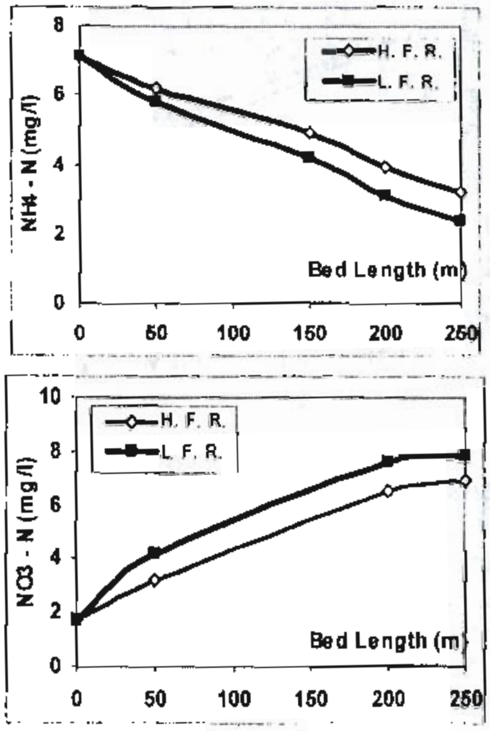


**Figure 5.** Variation of $NH_4^+$-N and $NO_3^-$-N concentrations along bed length.

$NO_3^-$-N concentrations detected in the inlet effluent were very low during the study period, ranging between 0.60 – 1.3 mg/l in summer and 0.8 – 1.4 mg/l in winter. The system showed high raise of the nitrate level in the treated polluted water. Figure 5 showed $NO_3^-$-N concentration along bed length that was at its highest at the effluent side reaching about 7.80 mg/l at the end of the LFR beds while it was 6.90 mg/l for the HFR beds. Some authors reported that CWs are usually efficient in reducing chemical oxygen demand, biochemical oxygen demand and suspended solids, but the corresponding removal efficiencies for nitrogen and phosphorus were often low [5],[9]. That might be because the carbon source was not available for denitrification, then lower overall nitrogen removal will result and/or the number of denitrifying bacteria in the CW systems was not high enough to release the nitrogen [15].

The influent range for Phosphorus ($PO_4^{3-}$) in the system was 1.90 – 3.50 mg/l. Figure 6 illustrates the effect of bed length and different type flow rates on $PO_4^{3-}$. The phosphorus assimilation in CWs depends on factors such as the influent phosphorus concentration, soil adsorption, the rate of internal biomass cycling, and the wetland age. The processes such as soil adsorption and peat accumulation control the long-term sequestration (i.e. capture) of $PO_4^{3-}$. Dunne et al. [17] demonstrated with the help of an intact soil/water column study that the phosphorus sorption parameters were significantly positive related to the amorphous forms of iron and aluminum oxides in soils. The plant contributes to treatment through uptake of nutrients and other wastewater constituents. $PO_4^{3-}$ behaves more conservatively than N in wetlands system because of the lake of an atmospheric sink. Dissolved $PO_4^{3-}$may be present in organic or inorganic forms and is readily transferred between the two forms, plant uptake of dissolved inorganic phosphorus is rapid. Removal was significantly higher in planted than unplanted system therefore, macrophytes were directly involved with the removal of 17% of orthophosphate and 10% of total phosphorus [18]. $PO_4^{3-}$ removal along the beds was clearly denoted with about 52.0% and its concentrations were the lowest at the end of CW beds of about 0.95 mg/l.

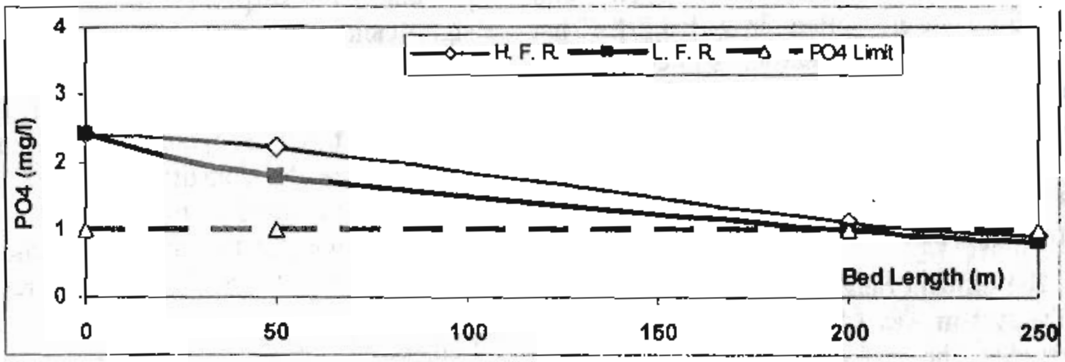


**Figure 6** Variation of $PO_4$ concentration along the bed length.

*Effect of Oxidation–Reduction on the Treatment of Trace Elements:* A number of metals are essential micronutrients at trace concentrations, but some of these metals occur in polluted waters at concentrations that are toxic to sensitive organisms. Metals in wastewater must be removed prior to final discharge to protect the environment from toxic effects. Aquatic plant roots in CW systems are capable of absorbing, concentrating, and in some cases, translocating toxic heavy metals and certain radioactive elements, thereby removing them from the water system [2]. Copper (Cu) was present in water as Cu (II). The ratio of free ionic to total dissolved copper is about (1%) and decreases with increasing organic loads and pH above neutrality. Cu forms relatively insoluble complexes with hydroxides, sulfides, and carbonates. With certain organic compounds, Cu may remain relatively soluble. Cu in the influent ranged from 0.03 to 0.06 mg/l. Figure 7 illustrates the effect of bed length and different type of flow rates on treatment efficiency of Cu. The concentrations of Cu were the lowest at the end of the LFR with about 38 % removal, while the removal HFR beds was about 34%.

The mean inlet and outlet levels of Zinc (Zn) are shown in Figure 7 illustrating Zn concentrations along bed length at different flow rates. The mean of inlet Zn concentrations in polluted water entering the cells was about 0.038 mg/l. The concentration of Zn was the lowest at the end of the treatment cells with about 42% and 48% removal in the HFR and LFR beds respectively.

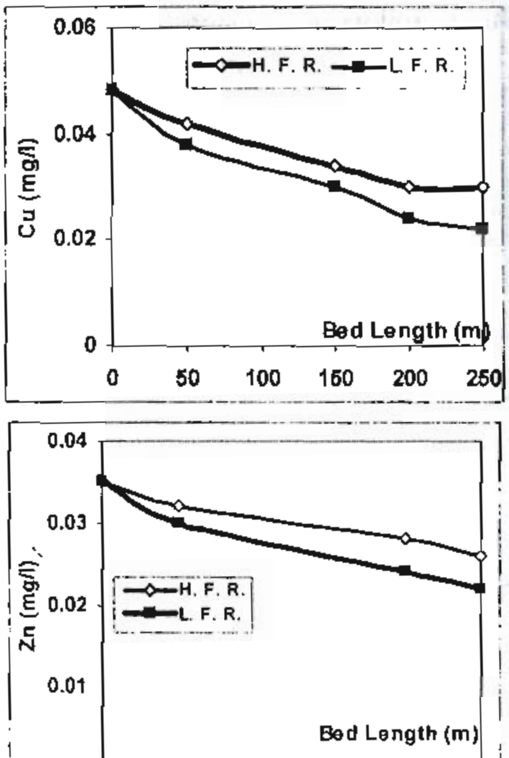


**Figure 7.** Variation of Cu and Zn concentrations along bed length

The sulfide form of Zn is highly insoluble and serves as a sink for Zn in the aquatic environment. Kaoru et al. [19] suggested that

Zn was removed mainly by physicochemical reactions. The seven times of increase hydraulic loading between the LFR and HFR resulted in only few percentage increase of removal efficiency of *the Trace Elements* and other pollutants. These could indicate that the high flow rate of 0.34 $m^3$ /$m^2$-d could be efficiently used to improve the quality of the low polluted water in the agricultural drains to the allowable limits.

Results of biological contamination removal of fecal coliform (FC) was also noted in the CW systems where the mean of the FC was reduced sharply from 28000 CFU/100 ml at inflow water samples to 555 CFU/100 ml at the outlet [20].

## 4. CONCLUSIONS

Free water surface (FWS) of constructed wetlands (CWs) of two rates were observed for improvement of a polluted water in a drain, in the eastern north of Delta Egypt, discharges its water in Manzala Lake that connected to the Mediterranean Sea. The hydraulic loadings of the experimental works conducted on high flow rate (HFR) of 0.344 $m^3$ $m^{-2}$ $d^{-1}$ (3340 $m^3$ /ha-d) and low flow rate (LFR) of 0.048 $m^3$ $m^{-2}$ $d^{-1}$ (480 $m^3$ /ha-d) and corresponding organic loading of 138 and 28 kg $BOD_5$/ha-day for HFR and LFR respectively.

The results of the experimental investigations indicated that there was slightly variation in most of the influent and effluent pollutants for different seasons for both HFR and LFR beds. The removal efficiencies of $BOD_5$ and COD were about 46.5 % at the end of the HFR beds and approximately 52.5% at the end of the LFR beds. Meanwhile, the removal efficiencies of TSS were about 89 and 82 % for the LFR and HFR beds respectively. The designed short hydraulic retention time for less than 2 days in the CWs minimized the potential for algal growth and therefore reduce the effluent TSS. The results also indicated that there was high reduction of the Ammonia Nitrogen ($NH_4^+$-N) through the both of HFR and LFR beds with removal efficiency of about 62.5 %, while there was increase in the Nitrate Nitrogen ($NO_3^-$-N) concentrations from 0.70 – 1.4 mg/l at the beginning of the both types of beds to about 6.9 - 7.80 mg/l at their ends. That might be because the carbon source was not enough for denitrification and/or the low number of denitrifying bacteria in the CW systems. The Phosphorus removal along the beds was clearly denoted with about 52.0% removal efficiency due to soil sorption and plant uptake. The mean removal efficiency for Trace Metals in the systems was about 53% for the Iron, 38 % Cupper, 48 % Zinc, and 52 %Lead.

The seven times of increase hydraulic loading between the LFR and HFR CWs systems resulted in only few percentage increase of removal efficiency of all pollutants. These could indicate that the high flow rate of 0.34 $m^3$ /$m^2$ - d (135 kg BOD/ha-d) could be efficiently used to improve the quality of the low polluted water in the agricultural drains to the allowable limits.

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