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PERFORMANCE OF A SURFACE FLOW CONSTRUCTED WETLAND SYSTEM USED TO TREAT SECONDARY EFFLUENT AND FILTER BACKWASH WATER

[COMPORTAMIENTO DE UN SISTEMA DE PANTANOS CONSTRUIDOS DE FLUJO SUPERFICIAL PARA EL TRATAMIENTO DE EFLUENTE SECUNDARIO Y DE RETROLAVADO]

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SUMMARY

The performance of a surface flow wetland system used to treat activated sludge effluent and filter backwash water from a tertiary treatment facility was evaluated. Samples were collected before and after vegetation removal from the system which consists of two densely vegetated settling basins (0.35 ha), an artificial stream, and a 3-ha surface flow wetland. Bulrush (*Scripus* spp.) and cattail (*Typha domingensis*) were the dominant plant species. The average inflow of chlorinated secondary effluent during the first two months of the actual study was 1.9 m^3 min^{-1} while the inflow for backwash water treatment ranged from 0.21 to 0.42 m^3 min^{-1}. The system was able to reduce TSS and BOD_5 to tertiary effluent standards; however, monitoring of chloride concentrations revealed that wetland evapotranspiration is probably enriching pollutant concentrations in the wetland outflow. Coliphage removal from the filter backwash was 97 and 35% during 1999 and 2000, respectively. However, when secondary effluent entered the system, coliphage removal averaged 65%. After vegetation removal, pH and coliphage density increased significantly ($p<0.05$) at the outlet of the wetland. This study showed that surface flow wetlands are an alternative technology for TSS, BOD_5, and turbidity removal from both secondary or backwash water. However, growth of bacteria populations or recovering of injured bacteria may occur.

Key words: TSS; BOD_5; constructed wetlands; wastewater; backwash water; microbial indicators.

RESUMEN

El comportamiento de un sistema de pantanos construidos de flujo superficial para el tratamiento de efluente secundario y de retrolavado proveniente de una planta de tratamiento terciario fue evaluado. Muestras de agua fueron colectadas antes y después de la remoción de la vegetación del sistema el cual consiste de dos cuencas de sedimentación (0.35 ha), un manantial artificial, y un pantano construido de flujo superficial de 3 ha. Las especies de plantas dominantes fueron Junco (*Scripus spp*.) y Typha (*Typha domingensis*). La tasa de flujo promedio de efluente secundario durante los primeros dos meses del estudio fue 1.9 m^3 min^{-1} mientras que la tasa de flujo de efluente de retrolavado fue de 0.21 a 0.42 m^3 min^{-1}. El sistema fue capaz de reducir SST y DBO_5 a estándares de calidad de efluente terciario; sin embargo, el monitoreo de la concentración de ion cloruro reveló que la evapotranspiración esta probablemente enriqueciendo las concentraciones de contaminantes en la descarga del sistema. La remoción de colifagos nativos presentes en el efluente de retrolavado fue de 97 y 35% durante el periodo de muestreo de 1999 y 2000, respectivamente. Sin embargo, cuando efluente secundario fue introducido al sistema, la remoción de colifagos promedio 65%. Los resultados del presente estudio muestran que los pantanos construidos de flujo superficial son una tecnología alternativa para remover SST, DBO_5 y la turbidez de efluente secundario y de retrolavado. Sin embargo, el crecimiento o el recobramiento de poblaciones bacteriales dañadas por cloración puede ocurrir.

Palabras clave: SST; DBO_5; pantanos construidos; agua residual; agua de retrolavado; indicadores microbiológicos.

INTRODUCTION

In conventional wastewater or drinking water treatment plants, backwash water results from periodic backwashing of single or mixed media filters used for removing organic matter, enteric pathogens, and other particulate matter from raw drinking water or activated sludge secondary effluent (Steven and Lester, 1994; Laurent *et al*., 1999; Persson *et al*., 2005; Khan and Subramania, 2007; Horan and Lowe, 2007). Consequently, backwash water without efficient treatment or recycling in treatment facilities may represent a public health risk (Koivunen *et al*., 2003). In order to protect public health, environmental protection agencies have regulated its recycling in conventional drinking water treatment plants to control disinfection resistant microbial pathogens and consequently waterborne diseases (USEPA 2002). In the wastewater treatment industry, constructed wetlands are considered an attractive technology to treat low strength domestic sewage and secondary wastewater effluents. Wetland technology has also offered an innovative approach for reduction, with different degrees of success, of a wide range of chemical pollutants (Grove and Stein, 2005; Matamoros *et al*., 2007; Winter and Kickuth, 1989). However, until recently few or not data existed on the efficacy of constructed wetland systems to treat backwash water; even though, one of the most mmon methods to treat backwash water has been settling in lagoon facilities (Montgomery, 1985). In 1997, two wetland systems were constructed at the Sweetwater Recharge Facility to treat backwash water from a tertiary wastewater treatment plant in Tucson AZ, USA. After soil aquifer treatment, wastewater is recovered from the aquifer at 1.6 x 10^7 m^3 $year^{-1}$ extraction rate to be deliver in golf course facilities, parks, schools, and residential sites. The objective of the actual study was to assess wastewater quality performance in the wetland system before aquifer recharge. Hence, physical, chemical, and microbial indicators for wastewater quality were evaluated in the wetland during secondary effluent and backwash water treatment from February to September 1999 and 2000. The actual paper presents the results of this monitoring study.

MATERIALS AND METHODS

The Research Site and Sampling

The research was conducted at the Sweetwater Wetland and Recharge Facility (SWRF) in Tucson, AZ. In this site (Figure 1), two polishing wetland systems referred to as East and West were designed in about 12.46 ha to reclaim backwash water from the City of Tucson Reclamation Plant. At this site, residual chlorine in secondary effluent at the pressure mixed media filters was on average 1 mg L^{-1}. After backwashing mixed media filters, the backwash effluent was kept free of chlorine additions. At the wetland facility, both the East or West polishing systems consist of a 3-ha wetland cell and a pair of settling basins vegetated with bulrush species (*Scirpus* spp.) and cattail (*Typha domingenses*). However, in the East Polishing System (EPS), wastewater flows briefly through an artificial stream before entering the 3-ha wetland cell for additional wastewater treatment. A sequence of islands of different sizes, shallow vegetated zones, and 1.2-m deep open water areas is the geometric configuration of the wetland to provide tertiary treated wastewater. After wetland treatment, polishing wastewater goes by gravity to four recharge basins, located at the vicinity area of The Santa Cruz River, for soil aquifer treatment. Eventually, drilling wells pump reclaimed water from the aquifer to the Pima County Roger Road Wastewater Treatment Facility (RRWTF) for chlorine disinfection and deliver in parks, schools, and golf course fields. In spite of both polishing systems were designed to treat backwash water, chlorinated secondary effluent from RRWTF was introduced for starting wetland operation in October 1997; on April 1998, the polishing wetland systems began to treat backwash water. In the winter 1999, wetland vegetation was harvested from the EPS; however, by the end of Spring a new complete plant canopy had taken its place. From February to September of 1999 and 2000, water samples were collected monthly from the EPS at the backwash splitter box (**1**), outlet of the south settling basin (**2**), both ends of the stream (**3** and **4**), and outlet of the wetland cell (**5**). Concurrently, measurements of water temperature (T^o), biochemical oxygen demand (BOD_5), total suspended solids (TSS), SO_4, Cl^-, total and free chlorine (Cl_2), turbidity, pH, native coliphages (NC), and total (TC) and fecal coliforms (FC) were conducted by using standard methods for water and wastewater analysis (APHA/AWWA/WEF, 1998).

Physical and Chemical Analysis

The 5-day incubation method (APHA/AWWA/WEF, 1998) was used for BOD_5 analysis with three replicates. Determination of TSS was conducted by filtering a known volume of sample through a pre-cleaned and pre-weighed glass fiber filter. TSS concentration was estimated reweighing the filter after a 24-h drying period at 100 ^oC. Sulfate was assessed by adding $BaCl_2$ to a known volume of sample and measuring the absorbance at 420 nm in a HACH DR/2000 spectrophotometer (Loveland, CO). Chloride was quantified by a chloride-specific electrode, a standard solution of a known amount of Cl and SO_4 was used as a sample to ensure that both analytical methods were working properly. Turbidity was measured with a portable turbidimeter (HACH, model 2100P, Loveland, CO) reading as Nephelometric Units

(NTU), previously calibrated with formazine standard solutions. A calibrated pH meter (model 8005, West Chester, PA) quantified water pH whereas the DPD (N,N-diethyl-p-phenylenediamine) indicator method (HACH Spectrophotometer, model DR/2000, Loveland, CO) was chosen for total and free chlorine (Cl_2) determination by using a distiller water blank like reference reading at 515 nm.

Coliforms and Coliphages

Total and fecal coliforms were analyzed within 4 h of sampling by membrane filtration using mEndo Agar Les and mFC culture media (DIFCO, Detroit, MI), respectively. The membrane filters were 47 mm diameter with a porosity of 0.45 μm (Millipore, Molsheim, France). Sample volumes of 0.1, 1, and 10 mL with two replicates per volume were assayed and incubated at 37°C for total coliforms and 44.5°C for fecal coliforms, results are reported as colony forming units (CFU). Native coliphages were quantified by the double layer agar method described by Adams (1959). A 1-mL aliquot from *Escherichia coli* ATCC 15597 (ATCC) culture, previously incubated at 37°C for 24 h in trypticase soy broth (DIFCO, MI), was combined with one mL of sample in a test tube containing molten overlay agar. This suspension was poured onto a layer of tripticase soy agar (DIFCO, MI), and incubated at 37°C for 18 h in order to enumerate the coliphage as plaque forming units (PFU) in two replicates. This method detects both somatic and male specific coliphages.

Statistical Analysis

The Statistical Package for Social Science 12 (SPSS Inc., Chicago ILL) was used to conduct the statistical analysis for physical, chemical and microbial data sets. Tests to determine significant differences between sampling periods and monitoring sites were conducted by two way ANOVA analysis. Because of extreme concentration values and high variability into microbial data sets, ANOVA analysis was conducted transforming microbial concentrations to base 10 logarithmic units ($\log_{10}$). The geometric mean was used as a centrality measure for observed microbial indicator distributions. Extent of data dispersion was represented by geometric coefficient of variation, $(10^{\wedge}(\sigma) - 1) \times 100$ where σ is the standard deviation of $\log_{10}$ transformed microbial concentration values. The physical/chemical data sets were analyzed without transformation.

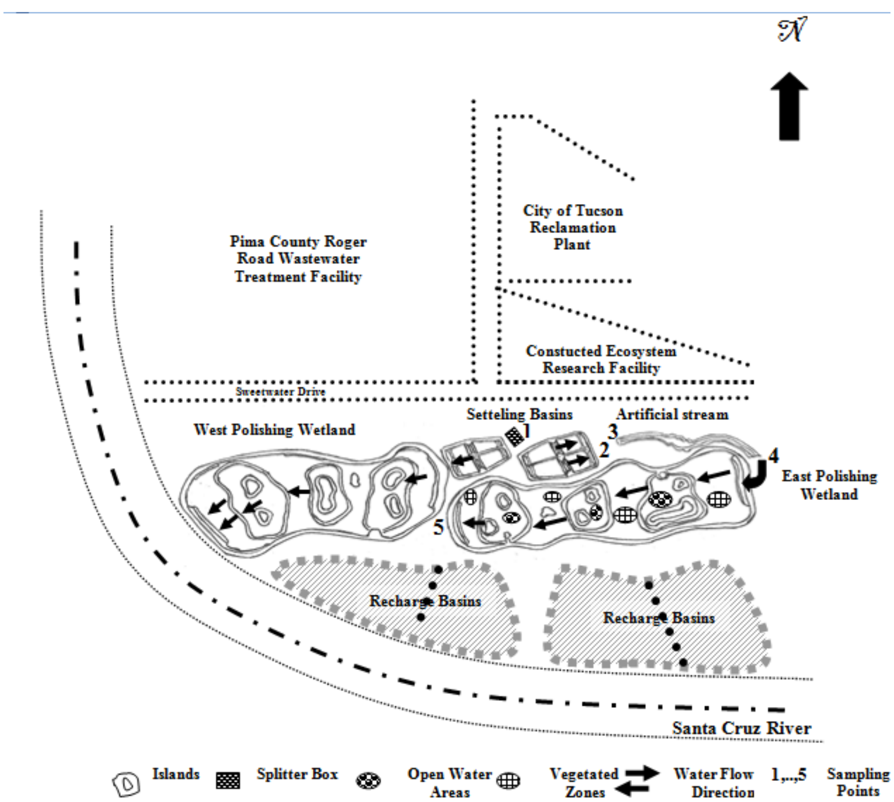

Figure 1.- Schematic representation of the Sweetwater Wetland and Research Facility in Tucson AZ.

RESULTS

Statistical Analysis

Standard Methods for Water and Wastewater Analysis (APHA/AWWA/WEF, 1998) reports the coefficient of variation (CV) per water or wastewater physical or chemical parameter analyzed per sample. For instance, CV for TSS should be lower than 33% at 15 mg L^{-1} concentration, however, if TSS concentration is about 242 mg L^{-1}, a CV lower than 10% is recommended. For coliforms enumeration, their analysis was conducted with three different volumes, accepting up to 15% difference between replicates, and contrasting CFU enumeration between analyzed volumes. For example, if at 0.1 ml TC average quantification was 10 CFU per mL, at 1 mL volume, the expected concentration should be 100 ± 15% CFU mL^{-1}. These quality criteria were revised for the analyzed parameters before conducting statistical determinations.

Hydrologic Conditions

An actual hydraulic residence time of 7.2 days was estimated by a tracer study in the East wetland cell (Vidales *et al*., 2006). During this study, February 12 to March 18, 1999, the wetland was receiving chlorinated secondary effluent at an average rate of 1.84 m^3 min^{-1}. From March 19 to 22, a mixture of chlorinated secondary effluent and backwash water was introduced into the East and West system changing to 100% backwash water at 0.42-m^3 min^{-1} flow rate, on March 23. This hydraulic condition was changed to 0.25 m^3 min^{-1} on June 30 and was held until September 21 when the EPS started to be drained for vegetation harvesting in the winter of 1999. The EPS returned to normal operation in February 2000 at an average inflow rate of about 0.32 m^3 min^{-1} of backwash water (Tucson Water, 1999 and 2000).

Sampling of Chlorinated Secondary Effluent

Two water samples were collected per sampling site during February and March, 1999. Influent BOD_5 and TSS concentrations were 29 and 21 mg L^{-1}, respectively, decreasing about 69% at sampling location **2** (Table 1). Turbidity reduction was very similar to BOD_5 and TSS performance with a 56% decrement from location **1** to **2**. At sampling site **2**, a significant increase of indicator bacteria was observed; in fact, TC inflow concentrations increased by a forty five-fold factor, approximately, at this sampling site. In contrast, the East wetland cell noticeably removed TC, FC, and NC reaching reductions about 91, 81 and 72%, respectively, from end to end of the 3-ha wetland.

Chloride was practically constant in the wetland system showing the lowest concentration at site **5**. Sulfate revealed a greater variability than Cl^- ranging its concentration between 122 and 144 mg L^{-1}. For pH, the lowest value was observed in the settling basin and the highest at splitter box. An average temperature of 22.75 ^oC was recorded at site **1** decreasing to 10.5 ^oC at wetland outlet, 3.66 ^oC below the average temperature for February and March 1999 recorded at the Tucson Meteorological Station (The Arizona Meteorological Network, AZMET, 2008). On February 19, total and free Cl_2 concentrations were 1.19 and 0.14 mg L^{-1}, respectively, in splitter box water. Both concentrations were below the method detection limit thereafter. On March 20, Cl_2 was undetected at any sampling point in the EPS.

Table 1. Two-sample average concentrations for parameters analyzed in the Sweetwater wetlands during secondary effluent treatment, February-March 1999.

Site	Total Coliforms	Fecal Coliforms	Coliphage	BOD_5	TSS	Cl^-	SO_4^{-2}	Turbidity	pH	Temperature
	CFU/100ml x 10^3		PFU/100 ml x 10^3	mg /L				NTU	$-Log_{10}$ [H]	^oC
1	0.36	0.064	4.89	29	21.5	126.0	128.5	17.9	8.17	22.7
2	16.21	8.51	7.24	9	6.5	125.0	133.0	7.8	7.22	20.2
3	11.74	4.26	7.94	7	8.0	122.5	127.0	7.6	8.15	19.0
4	6.48	1.17	6.02	7	5.0	127.0	144.5	6.3	7.95	18.0
5	0.58	0.22	1.69	8	5.0	116.5	122.5	2.8	7.49	10.5

Sampling of Backwash Effluent

Indicator Microorganisms.

Geometric mean concentrations for total coliforms, fecal coliforms, and coliphage observed at monitoring sites during backwash water study are presented in Figure 2. It can be clearly seen that TC and FC average concentrations increased in the settling basin. The remaining wetland treatment units resulted in further bacterial removal. At the system outflow, inflow NC concentrations decreased by about 97 and 35% in 1999 and 2000, respectively. Table 2 illustrates the high variability observed in microbial concentrations particularly in the first sampling period when geometric coefficient of variation (CV) ranged between 90 and 633% for TC and from 120 to 526% for FC. The ANOVA analysis revealed a significant difference for microbial indicator concentrations between sampling sites ($p<0.05$) but not for sampling periods ($p>0.05$).

BOD_5, TSS, Temperature, and Turbidity

Table 3 shows BOD_5, TSS, and turbidity descriptive statistics for 1999 and 2000 backwash water treatment. The CV values for those water quality parameters varied from 14.33 to 127.66 %; however, CV estimates during 2000 ranged between 19 to 76.10% for all the sampling sites. In contrast to the artificial stream and wetland cell, the settling basins were highly efficient for backwash water treatment. At this site, the average TSS, BOD_5 and turbidity were significantly reduced to 91-93%, 60-74%, and 65-78 %, respectively. These results are fairly lower than the estimates for the entire polishing system during both sampling periods, 90-96% for TSS; 84-89% for BOD_5; and 77-79% for turbidity, suggesting that TSS are more efficiently removed than BOD_5 and turbidity.

Cl^-, SO_4^{2-}, and pH

From April to September 1999, ANOVA analysis indicated that Cl^-average influent concentration was 141 mg L^{-1} increasing significantly ($p<0.05$) to 164 mg L^{-1} at site **2** (Figure 3). Thereafter, its concentration was 142 and 155 mg L^{-1} at site **3** and **4**, respectively. At **5,** a significant increase ($p<0.05$) of 40 mg L^{-1} above site **4** concentration was recorded. During the 2000 backwash sampling period, lower Cl^- concentrations than in 1999 were observed at monitoring sites. ANOVA analysis revealed a statistical difference ($p<0.05$) between both backwash water periods for Cl^-, in fact, a 16% difference between sampling periods for influent Cl^- concentrations at site **1** was estimated; for $SO_{4,}$ this estimate was 11 %. Table 4 gives coefficients of variation for Cl^- and SO_4; it seems clear that observed concentrations for both parameters showed a lower variation than the other water quality indicators (TC, FC, NC, TSS, BOD_5 and turbidity). For example, in 2000, the calculated CV at the system outflow was about 19 % for both Cl^- and SO_4 which is similar to the lowest CV estimated for TSS, BOD_5 and turbidity in the polishing system during backwash water treatment. In the same effluent, water pH ranged from 7.4 to 7.5 at sampling sites **1** to **3**; whereas, at the wetland outflow pH decreased, no significatively ($p>0.05$), to 7.35. Regarding residual Cl_2, its concentration was below the method detection limit at the sampling sites during the backwash water treatment study.

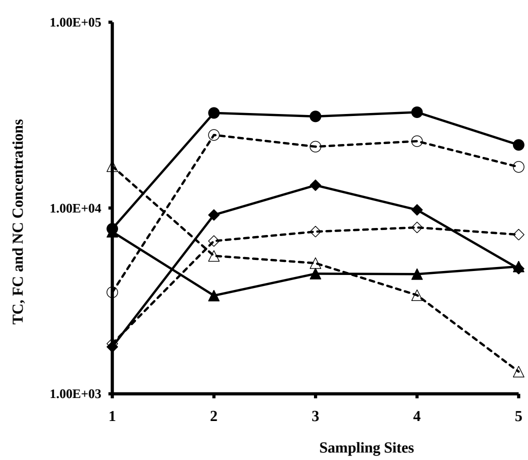

Figure 2.- Observed concentrations for TC (○,●; CFU/ 100 mL), FC (◊,♦; CFU/100 mL) and NC (Δ,▲; PFU/100

Table 2. Coefficients of variation (CV) for coliform, fecal coliform and coliphage concentrations observed at sampling sites in the East Polishing System during backwash water inflow.

Indicator	Coefficient of variation (%)									
	1999					2000				
	Sampling Site					Sampling Site				
	1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
TC	90	103	100	110	633	302	126	81.7	125	346
FC	120	410	182	188	526	145	119	122	107	468
NC	240	206	216	293	221	91	83	119	125	186

Table 3. Descriptive statistics of TSS (mg L^{-1}), BOD_5 (mg L^{-1}) and TUR (NTU) in samples collected from monitoring sites in the EPS during backwash water operation.

Variable	Number of samples		Min		Max		Median		Mean		CV (%)	
	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000
TSS (site 1)	6	7	98	7	380	278	159.5	115	190.66	115.57	127.66	69.17
TSS (site 2)	5	8	5	5	60	13	7	8.5	17.4	7.87	51.1	35.55
TSS (site 3)	6	8	5	5	30	16	5	6.5	10.33	7.50	37.2	49.37
TSS (site 4)	6	8	5	5	12	22	5	9.5	6.66	10.37	28.42	51.50
TSS (site 5)	6	8	5	5	10	30	6	8	7.0	11.62	14.33	76.10
Total Removal (%)							96.22	93.04	96.32	89.94		
BOD_5 (site 1)	6	7	71	78	252	207	112	161	127.66	144.71	52.03	35.31
BOD_5 (site 2)	4	8	10	25	136	46	30	38.5	51.5	37.37	111	19.07
BOD_5 (site 3)	5	8	12	22	63	45	32	39	37.2	36.87	52.38	21.42
BOD_5 (site 4)	6	8	10	19	42	42	26	30.5	28.42	31.25	58.29	25.81
BOD_5 (site 5)	6	8	9	19	21	36	14.5	21.5	14.33	23.62	31.03	23.83
Total Removal (%)							87.05	86.64	88.77	83.67		
TUR* (site 1)	6	7	30.36	16.3	344	308	120.5	142	150.85	142.62	63.90	64.96
TUR (site 2)	6	8	13	17	70	105	28.35	49.05	32.81	49.87	60.49	63.53
TUR (site 3)	6	8	20	27.9	113	123	32.8	59.65	44.26	57.9	77.36	56.76
TUR (site 4)	6	8	14	31.2	68	129	30.9	45.95	37.93	57.05	67.48	55.08
TUR (site 5)	6	8	5.28	21.4	64	44.5	31.1	35	31.8	32.9	81.84	26.32
Total Removal (%)							74.19	75.35	78.91	76.93		

*turbidity

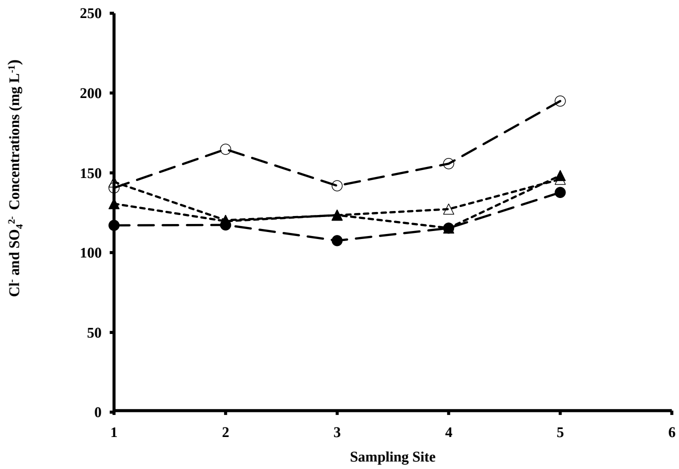

Figure 3.- Observed concentrations for Cl^- (○,●) and SO_4^{2-} (Δ,▲) in the Sweetwater wetlands during backwash treatment, 1999(○, Δ) and 2000 (●,▲).

Table 4. Coefficients of variation, CV (%) for Cl^- and SO_4^{2-} observed at sampling sites in the East Polishing System during backwash influent operation.

Indicator	1999 Sampling Site					2000 Sampling Site				
	1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Cl^-	17.31	15.72	9.80	9.50	12.83	14.18	9.33	11.24	9.29	19.14
SO_4^{2-}	13.41	6.03	7.46	10.45	14.52	24.42	13.80	13.89	14.46	19.13

DISCUSSION

Physical/chemical water quality indicators

For secondary effluent treatment, outflow water in the wetland met on average the 10 mg L^{-1} tertiary standard required by the Arizona Department of Environmental Quality (ADEQ) for BOD_5 and TSS. A significant increase of turbidity, BOD_5, and TSS occurred when secondary effluent was switched to backwash water at site **1**. At the wetland outlet, removal of BOD_5 was comparable to the 89 % reduction reported by Vrhovsek *et al.* (1996) in a subsurface flow wetland operated at 962 mg L^{-1} BOD_5 loading rate. Overall, BOD_5, and TSS removal in the East Polishing System was according to reported values for constructed wetlands operating across USA (Kadlec and Knight, 1996). In fact, the average TSS and BOD_5 at the outlet end of the system were lower than the 30 mg L^{-1} secondary standard limit established by the ADEQ for wastewater treatment.

Chloride is considered highly stable in most terrestrial environments. In wetlands, its total mass is approximately constant (Kadlec and Knight, 1996) because its incorporation in plant tissues is negligible (Hayashi *et al.*, 1998). Consequently, Cl^- has been used as a conservative tracer to estimate evapotranspiration in wetland ecosystems (Hayashi *et al.*, 1998). In the 3-ha polishing wetland, evapotranspiration may be a suitable mechanism for Cl^- augmentation during both backwash sampling periods when water flow rate was below 0.42-m^3 min^{-1}. Concentrations of Cl^- at both ends of the polishing wetland increased 25 and 19 % during backwash operation, before and after vegetation removal, respectively. ANOVA analysis indicated that only in 1999 was there a significant ($p<0.05$) statistical difference between inflow and outflow concentration from the 3-ha wetland cell. Sulfate is an essential nutrient for plants; thus, it can be retained by plant uptake in terrestrial environments; however, it is rarely a limiting factor for plant growth in wetlands (Kadlec and Knight, 1996). Its presence in high organic content environments induces production of hydrogen sulfide because SO_4^{-2} is an electron acceptor for sulfur-reducing bacteria (Maier, 2000). This microbiological mechanism probably was responsible for reduction of SO_4^{2-} in the settling basin, mainly observed during 1999 backwash water treatment. Similar to Cl^-, an increase of SO_4^{2-} concentration occurred at the outflow of the wetland.

Indicator microorganisms

Removal efficacies greater than 90 % for FC in surface flow wetlands receiving 10^4-10^6 UFC/100 inlet concentration loads have been reported (Kadlec, 2005). It appears that the amount of organic matter introduced into the settling basins is playing an important role for regrowth or recovery of injured coliform bacteria (Gerba, 2000; Bucklin *et al*., 2003; Bolster et al., 2005). Coliform bacteria such as *Klebsiella*, *Enterobacter*, and *Citrobacter* have shown ability to proliferate during wastewater treatment. For example, *Klebsiella* was found at high densities in the outflowing water from a treatment facility receiving municipal wastewater (Elmund *et al.*, 1999) apparently because of an increase of carbohydrates in the wastewater influent. F-specific RNA bacteriophages have been used as potential indicator for human enteroviruses instead of fecal coliforms and fecal streptococci (Stetler, 1984; Havelaar *et al*., 1993). A 90% removal of coliphage has been previously observed in constructed wetlands (Gersberg *et al.*, 1987; Chendorain *et al*., 1998); however, removals lower than 90% were reported by Karpiscak *et al.* (1995) in a duckweed (*Lemna* spp.) pond and by Gersberg *et al.* (1989) in non-vegetated wetlands. The extent of somatic and F-specific RNA coliphage replication in water has been discussed by several researchers (Jofre, 2009; Muniesa and Jofre, 2004; Woody and Cliver, 1997). Their findings suggest that coliphage replication is possible at host bacteria and virus concentrations uncommonly found in water environments. However, threshold concentrations may emerge because of bacteria growth. In the present study, coliphage removal in the settling basin, site **2**, showed a decrease from 98 to 65 % after vegetation harvesting in 1999. Probably, some mechanism associated to vegetation density or phage replication was responsible for undetectable coliphage removal from site **3** to **5** during the second backwash sampling period.

CONCLUSIONS

Apparently, the high organic removal and posterior mineralization in the settling basin promoted growth of TC and FC. Probably, repair of both groups of injury bacteria, after exposure to chlorination, was also occurring. Even, after vegetation removal, the surface flow constructed wetland system was able to treat filter backwash water to secondary effluent standards required by the Arizona Department of Environmental Quality for TSS and BOD_5. However, little removal of these parameters was observed in both the artificial stream and the 3-ha surface flow wetland cell. Similar to TSS, BOD_5 and turbidity, native coliphage concentrations showed a remarkable decrease at the settling basin apparently due to sedimentation of associated suspended solids. Interestingly, Cl^- and SO_4 increased their concentration in the wetland cell suggesting that some additional mechanism probably related with wetland evapotranspration is promoting pollutant enrichment. The findings of this study showed that settling basins are an acceptable facility for TSS, BOD_5, and turbidity removal from both secondary or backwash water; however, growth of bacteria populations or recovering of injured bacteria also may occur. The actual study has showed the complexity of a wetland environment where biological, physical, and hydrological conditions may explain pollutant performance during wastewater treatment.

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