
Volume 96, issue 7, July 2009
ISSN 0378-3774
96 (7) 1061–1180 (2009)
ELSEVIER
Agricultural
Water Management
an International Journal

Agricultural Water Management 96 (2009) 1175–1179

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Short communication

Evaluating the influence of wetland vegetation on chemical residence time in Mississippi Delta drainage ditches

R. Kröger [a,*], M.T. Moore [b], M.A. Locke [b], R.F. Cullum [b], R.W. Steinriede Jr. [b], S. Testa III [b], C.T. Bryant [b], C.M. Cooper [b]

[a] Department of Wildlife and Fisheries, Mississippi State University, Box 9690, Mississippi State, MS 39762, USA
[b] USDA-Agricultural Research Service National Sedimentation Laboratory, Water Quality and Ecology Research Unit, PO Box 1157, Oxford, MS 38655, USA

ARTICLE INFO

Article history:
Received 4 December 2008
Accepted 6 March 2009
Available online 5 April 2009

Keywords:
Drainage ditch
Residence time
Aquatic system

ABSTRACT

The presence of emergent vegetation within channelized aquatic environments has the capacity to provide a number of biological functions as well as alter the hydrology of the system. Vegetation within the channel exerts roughness, drag and friction on flowing water, reducing flow rates, increasing water depths and increasing hydraulic retention time. By increasing the hydraulic retention time, chemical residence time (CRT) is increased, thus improving the potential of pollutant mitigation. The study compared two geomorphologically similar drainage ditches, one vegetated and one non-vegetated to evaluate the effect obligate, in-stream wetland vegetation had on CRT. A fluoride (F^-) tracer was amended to both ditches with nutrients and sediments to simulate stormwater runoff event. The measured CRT of the vegetated drainage ditch was at least twice that of the non-vegetated ditch. These results suggest that with the presence of vegetation increasing CRT, chemical removal rates will improve, and as a result increase the possibility of microbial transformation, adsorption, and macrophyte assimilation. By dredging or clear-scraping ditches and removing the vegetative component, farmers and managers alike will increase water flows, decrease CRT and potentially increase pollutant loads into aquatic receiving systems.

1. Introduction

Aquatic vegetation is a ubiquitous feature of riverine landscapes, ranging from constructed wetlands and riparian floodplains to urban creeks and agricultural drainage ditches. Open agricultural ditches are considered wetland ecosystems as they possess the three main characteristics common to all wetlands: an ephemerally inundated hydroperiod, underlined by hydrosoils, which support obligate to facultative wetland species (Kröger, 2008). Wetland vegetation, whether emergent or submerged, provides valuable biological functions to wetland ecosystems. Some of these functions include phytoremediation of nutrients, pesticides and heavy metals (Cunningham and Ow, 1996; Salt et al., 1998; Cronk and Fennessy, 2001), rhizosphere stabilization (Andersen et al., 1993), symbiosis and surface area attachment for microbes, as well as providing habitat for fauna ranging from macroinvertebrates to birds (Hammer, 1992). An often overlooked function of wetland vegetation in the biological literature, is the physical capacity to increase the roughness or surface area of the respective channels, thus reducing water velocities, providing effective flood control and improving processes of sedimentation (Abt et al., 1994) and pollutant mitigation (Kröger et al., 2008). Vegetation type, as well as physical characteristics of the channel will significantly alter the channels roughness and thus affect chemical residence time (CRT) (Darby, 1999; Nepf, 1999). Chemical residence time is defined as the time it takes for a parcel or molecule of a specified chemical to move through the system. Thus, it is important to determine what influence in-stream vegetation plays on CRT in agricultural drainage ditches which serve as potential mitigation conduits between production landscape and aquatic receiving systems.

A ubiquitous management practice of agriculture is drainage: a management tool to rapidly move water away from cultivated land into aquatic receiving systems to increase trafficability and soil aeration. Often farmers will dredge or clear scrape these surface ditches, removing all vegetation from the drainage ditch channel as well as the channel sides to further improve farm drainage. This process reduces the roughness of the channel, allowing water to move more swiftly from the farm into adjacent receiving systems (Jadhav and Buchberger, 1995).

The effect of in-stream vegetation on altering roughness coefficients and CRT in creeks, streams and rivers is well

* Corresponding author. Tel.: +1 662 232 2914; fax: +1 662 915 5144.
E-mail addresses: kroger@olemiss.edu, rkroger@cfr.msstate.edu (R. Kröger).

0378-3774/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.agwat.2009.03.002

documented (Wu et al., 1999; Kouwen and Fathi-Moghadam, 2000; Li and Zhang, 2001). However, most often the literature is focused on identifying changes in roughness coefficients, and friction rather than identifying the role emergent, in-stream wetland vegetation plays in increasing CRT. Jadhav and Buchberger (1995) examined the role wetland vegetation played on wetland detention time, and showed that in times of dynamic conditions, such as runoff events entering a wetland, stem drag induced by aquatic plants predominates and wetland detention times increase with vegetation density.

The United States Geological Survey has provided a singular literature source (Barnes, 1967) where multiple examples of various rivers across the US have been characterized to provide roughness coefficients. This roughness coefficient is often called Manning's n and is a value given to a particular stream, river or channel reach to describe its retardation of water flow. However, there are no guidelines whether in-stream wetland vegetation alters CRT retention in surface drainage ditches, or documented evidence of the difference in CRT between a vegetated and non-vegetated (dredged) drainage ditch *in situ*. This study examined two *in situ* ditches, one vegetated and one non-vegetated, and highlighted the effect emergent, in-stream wetland vegetation played in altering CRT.

2. Materials and methods

2.1. Study site location

The Delta Conservation Demonstration Center (DCDC) in Metcalf, Mississippi, USA is a center which aims to educate farmers and public stakeholders on the effective use of best management practices on farms to reduce surface water pollutants, improve farm economics and increase water quality in the Delta of Mississippi. Within DCDC, a vegetated and non-vegetated surface drainage ditch were examined to evaluate the role in-stream wetland vegetation plays in altering CRT. Ideally, one ditch would have served initially as the vegetated ditch, and would have been subsequently modified by removing the vegetation and then examined as the non-vegetated ditch. However, being a functioning demonstration center, the vegetation could not be removed so the next best option was to compare two geomorphologically similar ditches on the same farm. Conceptually, in-stream drag, or friction can be divided into three components: soil grain roughness, form roughness and vegetative roughness (Wu et al., 1999). Both vegetated and non-vegetated ditches were underlain by highly organic Mississippi Delta Sharkey clays, rendering the soil grain roughness component difference negligible. Furthermore the two ditches were constructed by the same construction company, to similar dimensions. There were no significant differences between ditches in mean bank width (V: 6 ± 0.26 m; NV: 5.9 ± 0.31 m), mean channel width (V: 3.2 ± 0.24 m; NV: 3.13 ± 0.21 m) and length (320 m). Thus, the difference in form roughness between the two ditches was also negligible. The vegetated ditch was comprised of a mixture of common native, obligate, emergent wetland vegetation: *Typha latifolia* L., and *Sparganium americanum* Nutt., occurring at variable densities along the length of the drainage ditch. Density was established using a circular quadrat with an i.d. of 1 m. All stems were recorded within the quadrats, replicated on both upstream and downstream portions of the transect, and converted to per m^2. *T. latifolia* (Typhaceae) is a rigid wetland emergent (max ht: 2.2 m) that occurred in low–high stem densities (2–15.17 stems m^{-2}; max: 48.4) with 93% of the drainage ditch. Interspersed among *T. latifolia*, Burreed (*S. americanum*), a flexible wetland emergent (max ht: 0.4 m) occurred in moderate stem densities (5–5.86 stems m^{-2}), but had high stem densities when occurring in monospecific stands (13.27–22.9 stems m^{-2}; max: 45). There was no vegetation within the non-vegetated ditch. The significant difference in vegetation density between the two ditches enabled a specific evaluation of the effect of vegetative roughness on CRT.

2.2. Tracer amendment

A simulated storm runoff of nutrients and sediments was introduced to the non-vegetated ditch in mid-April 2006 and then to the vegetated ditch in early May 2006. Two 190 L mixing chambers were used to mix identical doses nutrients and sediments. In addition to nutrients, a fluoride (F^-) tracer was added to the slurry at 0.25 mg L^{-1} for both vegetated and non-vegetated ditches respectively to determine CRT. Dyes were not used because of aesthetics of the demonstration center, as well as possible interactions with spectrophotometric analysis of nutrient concentrations. Two FMI™ piston pumps delivered the nutrient-tracer slurry at 450 mL min^{-1} from mixing chambers to the exposed drainage ditch during the 7 h exposure. The sediment slurry was amended to the systems using a 3800 L mixing tank and an Atwood™ V500 (~1900 L h^{-1}) bilge pump for delivery. During the 8 h experiment, groundwater was pumped into the ditch inflow at a rate of 1135 L min^{-1} for the first 30 min (prior to nutrient-tracer-sediment addition), followed by a rate of 2270 L min^{-1} for the next 7 h (nutrient-tracer-sediment addition), and concluded with a rate of 1135 L min^{-1} for the final 30 min (no nutrient-tracer-sediment addition).

2.3. Tracer sampling and analysis

Eight sampling locations (0 m, 5 m, 10 m, 20 m, 40 m, 80 m, 160 m, and 320 m) were stratified longitudinally along each drainage ditch. Grab samples of ditch water were collected in 230 mL polyethylene cups (Fisher Scientific, Pittsburgh, PA) at 30-min intervals for 8 h, then again at 10 h, 16 h, 24 h, and 48 h at each of the eight spatial sampling locations. Collected samples were stored on ice immediately and returned to the laboratory for tracer analysis. Samples were filtered through a 0.45 μm Whatman cellulose membrane, and run through a Dionex Ion chromatograph (detection limit > 0.01 mg L^{-1}) fitted with a 7-anion detector column (IonPac ASH-HC). The ion chromatograph was also fitted with GP50 gradient pumps, a EC40 eluent generator and a CD25 conductivity detector. Retention times and concentration curves were assessed using Chromeleon chromatography workstation. Samples were bracketed with multi-level standard calibrations (0.5, 1, 2, 5 mg L^{-1}) and deionized water blanks were rinsed through after every 20th sample. Spatial gradients, and CRTs were analyzed using Pearson's correlations on F^- concentration and longitudinal distance from injection point within each respective drainage ditch. Comparisons between drainage systems were made with equal variance, two-tailed, Student's t-tests, at an alpha of 0.05.

3. Results and discussion

Examining the temporal data of F^- concentrations (Figs. 1 and 2) within the respective vegetated and non-vegetated drainage ditches shows the drainage ditches vegetated with a suite of obligate, emergent wetland vegetation had higher CRT than the geomorphologically similar non-vegetated system. Darby (1999) documented surfaces of streams covered by non-flexible and flexible riparian vegetation had significantly larger roughness coefficients than those which had no in-stream vegetation at all. An increase in roughness results in a decrease in flow rate and an increase in water depth and CRT. Fig. 1 plots the resultant slopes of linear regressions for F^- concentrations

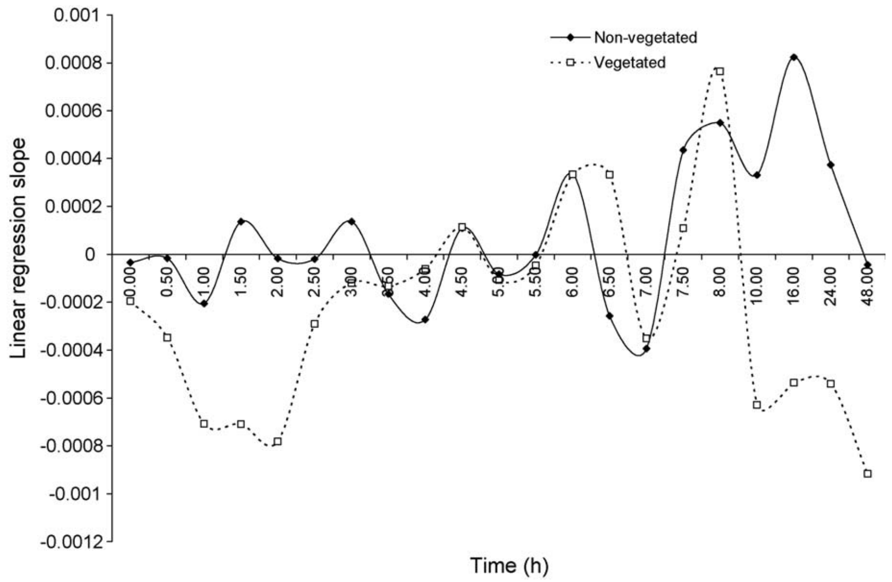

Fig. 1. Linear regression slopes for F^- concentration against spatial distance for each time step for vegetated and non-vegetated drainage ditches.

against spatial distance (0–320 m) along the respective drainage ditches for each time interval sampled. Negative slope values denote a decrease in concentration with distance, while a positive trend suggests concentrations are increasing with distance. Thus, the earlier a slope of concentration vs. distance tends positive, the lower the residence time within the ditch. Of the 21 time steps measured, only 8 had significant slopes where the F^- concentration increased or decreased with distance from the injection point (0 m). The majority of significant correlations for the non-vegetated ditch were positive and occurred at 7.5–>24 h time steps demonstrating the tracer influent peak moving through the system. However, there were only significantly negative correlations for the vegetated ditch from 0 h to 2.5 h, where high inflow and low outflow concentrations resulted in significantly negative slopes. The first time the regression slope is positive for the non-vegetated ditch is at 1.5 h, while for the vegetated ditch it is at 4.5 h (Fig. 1). Using these results, the non-vegetated ditch had an estimated CRT of 1.5 h while the vegetated ditch had a CRT three times as large, at 4.5 h.

Fig. 2A and B plotted the mean F^- concentrations between the four inflow sampling stations (0–20 m) and the outflow station (320 m) against the time steps sampled. The average F^- concentration of the four sampling stations over the course of the amendment (0–7 h) was 0.350 ± 0.0097 ppm for the non-vegetated ditch, and 0.405 ± 0.0105 ppm for the vegetated ditch. This average concentration represents the maximum concentration, with dilution, that should be seen at the ditch outflow. By determining how long it takes for outflow concentrations to be greater than the inflow average in each respective ditch will provide a second indication of CRT within the drainage ditches. There were no significant differences between initial inflow F^- concentrations between non-vegetated and vegetated drainage ditches ($t = -1.439$; $p = 0.1527$; Student's t-test, two-tail, equal variance). The solid line in each figure denotes the average concentration over 0–7 h for the four inflow stations for each ditch respectively. Fig. 2A and B show two important hydrological characteristics for each ditch. The first highlights the time taken for inflow concentrations to reach a stable equilibrium, and the second highlights the time taken for outflow concentrations to be greater than that of the mean inflow concentration over the course of the amendment. For the non-vegetated ditch (Fig. 2A), the inflow concentrations (0–20 m) equilibrate between 1 h and 3 h, where over the same time period the outflow concentration (320 m) increased to over the average inflow concentration for the first time, suggesting a CRT for the non-vegetated ditch of 1.5 h. In contrast the vegetated ditches' (Fig. 2B) inflow concentrations (0–20 m) equilibrate between 2.5 h and 4.5 h, whereby at the same time period the outflow concentration (320 m) peaked over the average inflow concentration, suggesting a 3.5 h CRT. These CRT estimations are limited as a result of the lack of *in situ* field replication between vegetated and non-vegetated ditches. Replication would have provided a reliable variability in CRT estimation between treatments, rather than a single estimate.

Kröger et al. (2008) demonstrated that small scale, artificially constructed ditches with similar physical characteristics of width, length and slope, but varying vegetation composition (one vegetated, one non-vegetated) showed markedly different and varied CRT. Vegetated ditches out performed non-vegetated ditches in increasing time to peak (T_p) as well as the return period, or time to base (T_b) of chemographs plotting movement of a pollutant through the ditch system. The T_p gives an accurate estimate of the CRT of the system, i.e. how long a molecule of water takes to pass through the system. Chemical residence time is an important factor in various wetland systems, indirectly affecting biological functions and is a key factor in microbial removal in tertiary treatment reed beds (Garcia et al., 2003). Similar results found less faecal coliform inactivation in a wetland treatment system operating with a shorter HRT (Ottova et al., 1997). Schulz et al. (2003) demonstrated removal rates of total phosphorus and total nitrogen from rainbow trout effluent were positively correlated to HRT—i.e. the longer the HRT, the higher the removal rate. Toet et al. (2005) highlighted that nitrogen and phosphorus removal efficiency by harvesting *Phragmites australis* and *Typha* shoots was enhanced with increased HRT (0.3–9.3 days), with annual mass input reduced through harvest by 7–11% and 4.5–9.2% for nitrogen and phosphorus respectively. Chen et al. (2008) used variable HRT on post treatment wastewater from hog farms. Results showed that a higher HRT (7 days vs. 2 days) reduced effluents of chemical oxygen demand, biological oxygen demand and suspended solids below wastewater discharge limitations in Taiwan. By understanding the fundamental physical phenomenon of hydrology in wetlands and its interaction with in-stream vegetation (Kadlec, 1989), a context for understanding the

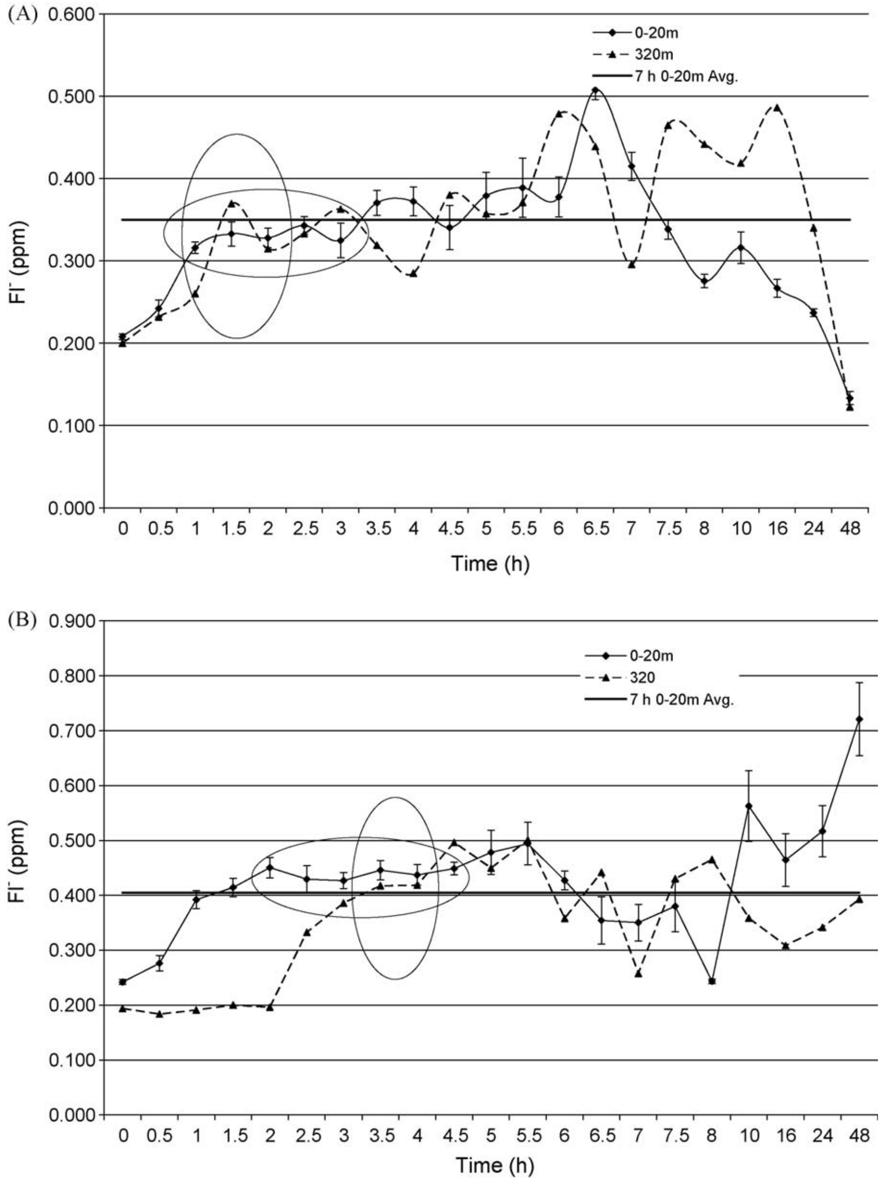

Fig. 2. Temporal concentrations of F^- through time for two spatial locations within the non-vegetated (A) and vegetated (B) drainage ditches. Sampling stations 0 m, 5 m, 10 m, and 20 m, were averaged (±S.E.) to provide a single sampling location, and 320 m was the effluent outflow. Bold line is the 0–7 h F^- mean for the 0–20 m inflow for each respective ditch. Ellipses show the first time F^- concentrations are above average and the first stable equilibrium.

interaction between physical, biological and chemical processes that control wetland ecosystems can be formulated.

4. Conclusions

A simple, valuable tool to aid in pollutant mitigation is the benefit derived from in-stream wetland vegetation. Besides providing surface area for assimilation, adsorption, and microbial attachment, plants are beneficial for the hydrology of the system. Plants effectively slow water velocities, increase turbulence and water depths and thus increase hydraulic retention times. Vegetated drainage ditches, in the field, increased CRT over non-vegetated or "managed" ditches, effectively providing an environment for improved contaminant remediation. As primary intercept wetlands, these ditches have the ability to transform and assimilate contaminants and reduce impacts on downstream aquatic ecosystems. However, by dredging or clear-scraping ditches and removing the vegetative component, farmers and managers alike will increase water flows, decrease CRT and likely increase pollutant loads into receiving aquatic systems. Future research will investigate the relationship between drainage management, environmental benefits and agricultural yield production.

Acknowledgements

The authors would like to thank the cooperation of DCDC, and the hard work and dedication of the Water Quality and Ecology Unit at the National Sedimentation Laboratory. The authors would also like to thank the valuable comments by two anonymous reviewers.

References

Abt, S.R., Clary, W.P., Thornton, C.I., 1994. Sediment deposition and entrapment in vegetated streambeds. J. Irrig. Drain. Eng. 120, 1098–1111.

Andersen, T.A., Guthrie, E.A., Walton, B.T., 1993. Bioremediation in the rhizosphere. Environ. Sci. Technol. 27, 2630–2636.

Barnes, H.H., 1967. Roughness characteristics of natural channels. In: U.S. Geological Survey, Water Supply Paper 1849, U.S. Government Printing Office, Washington.

Chen, S.W., Kao, C.M., Jou, C.R., Fu, Y.T., Change, Y.L., 2008. Use of a constructed wetland for post treatment of swine wastewater. Environ. Eng. Sci. 25, 407–417.

Cronk, J.K., Fennessy, M.S., 2001. Wetland Plants: Biology and Ecology. Lewis Publishers, New York, NY, USA.
Cunningham, S.D., Ow, D.W., 1996. Promises and prospects of phytoremediation. Plant Physiol. 110, 715–719.
Darby, S.E., 1999. Effect of riparian vegetation on flow resistance and flood potential. J. Hydraul. Eng. 125, 443–454.
Garcia, J., Vivar, J., Aromir, M., Mujeriego, R., 2003. Role of hydraulic retention time and granular medium in microbial removal in tertiary treatment reed beds. Water Res. 37, 2645–2653.
Hammer, D.A., 1992. Designing constructed wetlands systems to treat agricultural nonpoint source pollution. Ecol. Eng. 3, 1–34.
Jadhav, R.S., Buchberger, S.G., 1995. Effects of vegetation on flow through free water surface wetlands. Ecol. Eng. 5, 481–496.
Kadlec, R.H., 1989. Overland flow in wetlands: vegetation resistance. J. Hydraul. Eng. 116, 691–706.
Kouwen, N., Fathi-Moghadam, M., 2000. Friction factors for coniferous trees along rivers. J. Hydraul. Eng. 126, 732–740.
Kröger, R., 2008. Chapter 13: Agricultural wetlands. In: Russo, R.E. (Ed.), Wetlands: Ecology, Conservation and Restoration. Nova Publishers, New York, NY, pp. 391–406.
Kröger, R., Cooper, C.M., Moore, M.T., 2008. A preliminary study of an alternative controlled drainage strategy in surface drainage ditches: low-grade weirs. Agric. Water Manage. 95, 678–684.
Li, Z., Zhang, J., 2001. Calculation of field Manning's roughness coefficient. Agric. Water Manage. 49, 153–161.
Nepf, H.M., 1999. Drag, turbulence and diffusion in flow though emergent vegetation. Water Resour. Res. 35, 479–489.
Ottova, V., Balcarova, J., Vymazal, J., 1997. Microbial characteristics of constructed wetlands. Water Sci. Technol. 35, 117–123.
Salt, D.E., Smith, R.D., Raskin, I., 1998. Phytoremediation. Annu. Rev. Plant Physiol. Plant Mol. Biol. 49, 643–668.
Schulz, C., Gelbrecht, J., Rennert, B., 2003. Treatment of rainbow trout farm effluents in constructed wetland with emergent plants and subsurface horizontal flow. Aquaculture 217, 207–221.
Toet, S., Bouwman, M., Cevall, A., Verhoeven, J.T.A., 2005. Nutrient removal through autumn harvest of *P. australis* and *T. latifolia* shoots in relation to nutrient loading in a wetland system used for polishing sewage treatment plant effluent. J. Environ. Sci. Health A 40, 1133–1156.
Wu, F.C., Shen, H.W., Chou, Y.J., 1999. Variation of roughness coefficients for unsubmerged and submerged vegetation. J. Hydraul. Eng. 125, 934–942.