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NUTRIENT AND METAL UPTAKE IN WETLAND PLANTS AT STORMWATER DETENTION PONDS

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Summary

Nutrients and metals were analysed in tissues of various wetland plants growing in stormwater detention ponds in Denmark. Nutrient and metal concentrations in below and aboveground tissues were compared to the concentrations of the adjacent sediment. The results showed accumulation of heavy metals in the roots with no significant transport to the aboveground tissues, while macroelements such as P and K were accumulated in the shoots. Concentrations of Zn, Cu, Ni and Pb were correlated with concentrations of these elements in the sediment. There were also significant differences in heavy metal accumulation in the roots of different plant species.

Keywords: phytoremediation, plant uptake, heavy metals, wetland, stormwater.

Introduction

Due to washing of pollutants from impervious surfaces, stormwater runoff presents dispersed pollution of surface and ground waters. The most common pollutants in stormwater are biodegradable organic matter, nutrients, heavy metals, organic micropollutants (e.g.: PAH, PCB), suspended solids and pathogenic microorganisms (Pitt *et al.* 1999, Bulc & Vrhovšek 2003). Stormwater runoff is often released to the environment without any treatment and causes pollution of receiving water bodies including erosion and sediment deposit. However, especially in northern Europe and in US several treatment systems are in use in order to retain and treat stormwater runoff; namely infiltration systems; grass swales, filter strips, constructed wetlands, and detention ponds (Deutsch, 2003). The last two are among the most used and reliable technologies, achieving relatively good and consistent pollutant removal (Hvitvet-Jacobsen et *al.* 1994, Scholes et *al.* 1998, Somes et *al.* 2000). Wet detention ponds and constructed wetlands are planted with different macrophyte species, which contribute to pleasant appearance of a system, attract fauna and can play an active role in the removal of pollutants (Brix, 1997). The results of a study on different plant and media biofilters for stormwater treatment by Bratieres et al. (2008) showed enhanced removal of nitrogen, phosphorous and suspended solids from stormwater mainly due to the vegetation and a marked variation among the species. Sand filters planted with reed for stormwater treatment also showed good initial performance in removal of suspended solids and heavy metals (Bulc & Vrhovsek, 2003).

Stormwater treatment facilities are adapted to the characteristics of stormwater runoff, which are the stochastic nature according to precipitation pattern and high variation in pollutant loads. After first flush at the beginning or a rain event with lower flows and high pollutant concentrations, pollutants are mixed into large water volumes, resulting in low concentrations. Stormwater treatment facilities are therefore confronted also with challenge of reduction of rather low pollutant concentrations to even lower levels (Vollertsen et *al.* 2008). It is known that in the treatment of lower polluted waters, plant uptake of pollutants can act an important role (Vymazal, 2004).

Materials and Methods

Plants were sampled in three stormwater treatment systems established as part of a European LIFE project TREASURE in the cities of Aarhus, Silkeborg and Odense, in Denmark. The three systems are impermeable ponds with permanent water volume and a storage volume above it that fluctuates according to the precipitation events. Each of three ponds consists of silt trap at the inflow, open water pond with wetland vegetation and sand filter planted with *Phragmites australis* at the outflow. Because the capacity of simple stormwater wet detention ponds to remove colloidal and dissolved pollutants like phosphorous and dissolved heavy metals is rather low (Vollertsen et *al*, 2008), additional technologies have been implemented into the three investigated systems. In the pond at Aarhus, the additional technology was enrichment of bottom sediments with iron salts, in Odense it was the incorporation of sorption filters at the final outflow from the system and in the pond at Silkeborg it was the addition of aluminium coagulants at the inflow.

The plant selection and the planting scheme for the three systems was decided according to the physical features of each wet pond, the operational characteristics and the esthetical needs, to ensure functionality while maintaining a "natural" appearance and enhancing the ecological and educational value of the sites by attracting fauna, best integration to the landscape and by encouraging the local public to visit the site.

Odense Facility

The wet detention pond at Odense is located in an industrial area in the outskirts of the city. The system receives runoff water collected from a light industry catchment with a surface area of 27.4 ha (impermeable area of 11.4 ha). The average annual precipitation is around 660 mm and an estimated runoff flow of 55,500 m^3 $year^{-1}$.

The system was planted with selected plant species, which included plants that should help counteract clogging of the sand filter, namely common reed (*Phragmites australis*). Other species were selected mainly for aesthetic reasons but also had the potential to improve the removal of pollutants. They were planted along the edges and within the wet pond. The plant species selected for the site included *Phragmites australis* (planted on the sand filters and part of a bank), *Typha latifolia*, *Rumex hydrolapathum*, *Typha angustifolia*, *Ranunculus lingua*, *Typha minima*, *Iris pseaudacorus*, *Sagittaria sagittifolia*, *Caltha palustris*, *Alisma lanceolatum* and *Nymphea alba/Nuphar luteum*.

Aarhus Facility

The facility receives run off from an urban residential catchment with a total surface of ca. 57 ha, where 50% of the area is considered impermeable. The average yearly precipitation in the area is around 660 mm and an estimated run-off flow of around 130,000 m^3 $year^{-1}$.The pond was built adjacent and parallel to the receiving lake, in a residential neighbourhood and is integrated into a recreational area, with bird observation towers, bicycle and walk paths.

The plant selection for the system was in accordance with the existing plant species in the receiving lake. The banks of the facility in Aarhus were left unplanted and *Phragmites australis* was planted in the sand filter. The system's design included three high ground zones (polders) that were planted with *Schoenoplectus lacustris* to resemble the neighbouring receiving lake to minimize visual impact.

Silkeborg facility

The facility is located in an urban park stretching into the city of Silkeborg and receives runoff from a catchment with a surface of 22 ha where ca. 9 ha are considered impermeable. Approximately one third of the runoff water originates from a local housing area and the remainder run off is collected from a highway. Plants were planted along the basin banks and on the transversal sand baffles in the basin. The plant species selected for the site included *Phragmites australis, Typha latifolia, Rumex hydrolapathum, Typha angustifolia, Ranunculus lingua, Typha minima, Iris pseaudacorus, Sagittaria sagittifolia, Caltha palustris, Scirpus* *maritimus, Sparganium erectum*, *Alisma lanceolatum, Stratiotes aloides* and *Nymphae alba/Nuphar luteum*.

Sampling

Water, sediment and plant samples were taken in 2008 and 2009 and analysed for nutrients, heavy metals and micropollutants. In this paper results on plant analyses and their relation to sediment concentrations are presented.

Flow or time proportional water samples were taken by automatic samplers installed at the inlet, in the open water area of the wetponds and after the sand filters. Water quality parameters were measured according to Standard methods (APHA, 2005). Heavy metals were analysed using ICP-OES. The water quality characterization of the runoff water flowing to the three catchments showed the presence of TSS, organic matter, nitrogen, phosphorous, and some heavy metals, among them, Pb, Zn, Cd and Cu and organic micropollutants.

Sediment samples were taken in transects along the flow of each pond with an aluminium grader. Samples were collected and stored in plastic containers and analysed for organic content and metals according to Standard methods (APHA, 2005). Plant species planted at each site were sampled and separated into plant organs in order to evaluate the concentrations of metals in different plant tissues. Refrigerated plant samples were transported to the laboratory in plastic bags and washed upon arrival with tap water and dried at 80°C until constant weight. To analyse metals in the sediment and plant samples, dried samples were pulverized and approximately 250 mg of material was digested using 4 mL HNO_3 (69% v/v) and 2 mL H_2O_2 in a microwave oven (Anton Paar, Multiwave 3000) for one hour. After digestion samples were diluted and analysed for metals by ICP-OES. In sediment and plant samples P, Fe, Mn, Ca, Na, K, Al, Pb, Zn, Cd, Ni, Cr, and Cu were analysed.

Results

Nutrient and metal analyses in plants sampled at the three upgraded stormwater wet detention ponds showed different patterns in nutrient and metal accumulation between plant tissues as well as between plant species (Table 1).

P concentrations were in the same range comparing the species sampled in the three ponds as well as between above and belowground tissues. However, *C. palustris* accumulated higher concentrations of P compared to other species in the shoots and *S. lacustris* in the roots. Also, in *R. lingua*, *P. australis* and *I. pseudacorus,* P concentrations tend to be a bit higher in the shoots.

C. palustris accumulated the highest concentration of K in the shoots (52±5.3 mg g^{-1} DW). Also *Typha* sp., *I. pseudacorus* and *S. errectum* contained higher K concentrations in the shoots compared to the other species.

Iron was accumulated in the roots; the concentrations were highest in *C. palustris* and *S. errectum*. Mn and Ca concentrations were mainly in the same range in shoots and roots, while Na concentrations were variable and did not show a clear distribution pattern in different plant tissues. Heavy metals were accumulated in the roots with Zn in the highest concentrations, followed by Cu. There was no significant transport of heavy metals into the aboveground parts. In the majority of species Pb was detected only in the roots, while the concentrations in the aboveground tissues were below detection limit in all species except in *T. minima*. The highest concentrations of Zn, Ni and Cu were measured in roots of *R. hydrolapathum* and *T. latifolia*. Cu was accumulated also in the roots of *P. australis*, *T. angustifolia* and *T. minima*. Cr showed different accumulation pattern between the species and was accumulated in the roots of *S. lacustris* and *R. lingua*, which otherwise contained similar concentrations of heavy metals like other species.

High standard deviation in Zn, Ni and Cu root concentrations in *Rumex* indicate a marked difference in heavy metal concentration between the two ponds, where the species was sampled. While *Rumex* in the pond at Silkeborg contained relatively low heavy metal concentrations, the concentrations of Pb, Zn, Ni and Cu in the *Rumex* roots at Odense were very high, namely 144; 4,700; 180 and 4,400 µg g^{-1} DW for Pb, Zn, Ni and Cu, respectively (results not shown). Approximately two-times lower concentrations were detected in *P. australis* roots and three-times lower in *Typha* sp. roots at the pond at Odense.

Table 1. Mean nutrient and metal concentrations (± standard deviation) in the roots and shoots of plant species sampled at three stormwater wet detention ponds.

Species	plant part	P	K	Fe	Mn	Ca	Na	Pb	Zn	Ni	Cr	Cu
		mg g^{-1} DW						µg g^{-1} DW				
Caltha palustris	Shoot	12±2.5	52±5.3	1.7±0.49	2.1±0.88	10±1.4	11±6.6	BDL	132±63	2.4±0.52	4.3±1.6	11±4.9
	Root	4.7±1.2	6.6±4.5	23±5.7	2.0±1.8	12±0.60	6.2±5.2	4.9±3.4	250±87	6.2±1.5	11±1.9	25±6.0
Iris pseudacorus	Shoot	5.5±0.96	33±7.0	0.48±0.33	0.56±0.32	13±5.5	1.5±0.29	BDL	26±7.2	1.1±0.69	2.0±0.89	5.3±4.5
	Root	3.9±1.4	18±10	2.8±2.7	0.36±0.50	8.4±2.6	3.0±1.3	1.1±0.66	63±42	2.4±0.98	5.8±3.1	17±21
Phragmites australis	Shoot	3.6±1.5	16±6.6	0.32±0.23	0.32±0.22	2.8±2.2	0.88±0.49	BDL	43±35	0.64±0.43	2.5±2.4	4.2±4.3
	Root	2.8±1.0	10±4.8	7.1±8.00	1.2±2.9	3.7±4.9	3.5±2.2	8.3±23	223±515	11±28	9.8±6.6	161±559
Ranunculus lingua	Shoot	4.7±0.55	15±3.2	1.7±0.74	3.1±0.39	21±3.7	9.1±1.8	BDL	95±31	2.5±1.2	4.5±2.2	9.8±3.7
	Root	3.6±0.71	7.7±4.1	14±8.0	1.3±1.2	8.8±3.9	3.9±2.4	1.6±1.2	99±67	7.2±5.3	23±22	19±11
Rumex hydrolapathum	Shoot	3.3±0.82	18±4.6	0.43±0.41	0.51±0.33	15±8.5	2.6±0.84	BDL	38±37	1.3±1.8	1.1±0.50	14±19
	Root	3.0±1.05	10±4.9	8.0±11	1.2±1.5	9.0±3.2	3.4±3.0	12±40	441±1283	17±50	5.5±7.3	359±1219
Scirpus lacustris	Shoot	5.7±0.77	18±5.7	0.19±0.048	1.8±0.94	5.0±1.5	11±5.6	BDL	28±3.4	0.61±0.62	2.7±1.1	BDL
	Root	7.8±3.2	13±10	13±13	0.49±0.36	3.6±2.3	7.2±3.1	1.2±0.50	112±102	8.3±5.3	38±17	8.6±9.5
Scirpus maritimmus	Shoot	4.7±1.4	18±6.5	0.69±0.38	0.83±0.71	3.2±2.2	9.7±2.7	BDL	25±8.3	0.94±0.56	2.0±1.1	6.0±3.1
	Root	4.3±1.4	12±7.1	18±21	0.94±0.54	3.5±1.3	6.5±1.8	1.6±1.0	95±72	5.4±2.8	19±11	12±5.3
Sparganium erectum	Shoot	8.0±0.97	33±7.0	2.0±0.89	2.6±1.5	11±2.9	11±1.6	BDL	61±19	2.6±1.7	3.9±2.3	12±2.0
	Root	4.1±0.62	22±7.8	25±9.7	3.8±3.8	6.4±2.0	6.0±1.3	BDL	86±58	4.1±4.6	11±7.3	8.2±4.4
Typha angustifolia	Shoot	5.4±0.89	33±11	0.22±0.15	0.68±0.29	6.7±2.3	4.3±1.2	BDL	20±7.8	1.2±0.63	1.2±0.42	9.0±2.4
	Root	5.2±1.9	28±13	9.7±8.1	0.93±0.94	7.3±3.8	7.8±3.4	6.9±15	222±371	9.6±16	7.0±6.0	168±412
Typha latifolia	Shoot	5.4±0.23	27±0.51	0.19±0.025	0.62±0.060	9.1±0.59	2.9±0.39	BDL	41±8.6	3.4±0.26	1.0±0.38	19±2.4
	Root	6.3±2.1	26±7.5	14±9.5	0.40±0.34	10±4.5	11±3.3	27±26	617±535	26±23	8.4±3.7	637±616
Typha minima	Shoot	4.9±0.83	28±7.8	0.27±0.096	0.78±0.18	8.5±2.6	6.5±2.0	1.6±1.5	26±7.9	0.70±0.61	2.1±1.2	14±20
	Root	4.8±2.2	12±12	13±10	0.86±0.67	11±3.0	9.8±4.7	7.6±20	206±257	6.7±9.2	11±6.8	93±241

Heavy metal concentrations in the roots were compared to the concentrations in the sediment for each pond. The concentration ratio of plant roots to sediment is named Concentration Factor (CF). Average CFs and their range for each species from all sampling sites are shown in Table 2. CFs that are higher than one, indicate accumulation of the element in the plant tissue.

The majority of CFs for heavy metals in investigated plants was below one; however the standard deviation was high, indicating different accumulation depending on the sampling site. According to the results on water and sediment analyses (not shown here) the pond at Odense received the highest heavy metal loads and consequently accumulated the highest heavy metal concentrations in the sediment. The concentrations in the pond at Aarhus were lower and the lowest in the pond at Silkeborg, for water as well as for the sediment.

There was a marked difference between sampled species: certain species concentrated higher heavy metal concentrations in the roots compared to the others. The highest CFs were reached for Zn and Cu. Zn was accumulated especially in *C. palustris*, *P. australis*, *R. hydrolapathum* and *Typha* sp., but occasionally also in other species. Similar pattern like for Zn also occurred in Cu accumulation. Cr was accumulated in *R. lingua* and *S. lacustris* in concentrations higher compared to the sediment.

Table 2. Concentration factors of heavy metals in investigated plant species. Average and range (in brackets) are given.

	Pb	**Zn**	**Ni**	**Cr**	**Cu**
C. palustris	0.71 (0.15-1.22)	1.66 (0.93-2.30)	0.34 (0.22-0.45)	0.38 (0.29-0.48)	1.47 (1.04-1.94)
I. pseudacorus	0.15 (0.15-0.15)	0.50 (0.23-1.34)	0.15 (0.11-0.27)	0.19 (0.10-0.37)	0.67 (0.38-1.17)
P. australis	0.51 (0.15-0.99)	1.05 (0.45-2.37)	0.78 (0.16-4.26)	0.38 (0.16-0.86)	0.60 (0.11-1.44)
R. lingua	0.28 (0.15-0.68)	1.02 (0.77-1.12)	0.62 (0.47-0.85)	1.33 (0.69-2.00)	1.58 (0.93-2.13)
R. hydrolapathum	0.24 (0.15-0.84)	1.43 (0.13-4.46)	1.08 (0.01-5.86)	0.24 (0.02-0.44)	1.53 (1.05-2.35)
S. lacustris	0.13 (0.09-0.21)	0.77 (0.22-1.32)	0.51 (0.27-0.70)	1.26 (1.03-1.39)	0.10 (0.04-0.18)
S. maritimmus	0.31 (0.15-0.50)	1.07 (1.04-1.09)	0.37 (0.31-0.40)	0.83 (0.58-1.27)	1.01 (0.99-1.05)
S. erectum	0.15 (0.15-0.15)	0.91 (0.74-1.06)	0.42 (0.28-0.67)	0.55 (0.37-0.83)	0.67 (0.42-0.84)
T. angustifolia	0.25 (0.15-0.71)	1.05 (0.59-1.75)	0.65 (0.15-1.77)	0.34 (0.19-0.70)	0.96 (0.33-2.85)
T. latifolia	0.29 (0.24-0.33)	1.02 (0.98-1.06)	1.45 (1.33-1.56)	0.19 (0.17-0.21)	0.43 (0.42-0.43)
T. minima	0.18 (0.15-0.39)	1.07 (0.84-1.93)	0.38 (0.15-1.05)	0.33 (0.15-0.73)	0.60 (0.15-0.97)

The highest CFs were measured in *R. hydrolapathum* growing in the pond at Odense, namely 4.46, 5.86 and 2.35 for Zn, Ni and Cu. Also *Phragmites* had high maximum concentration factor for Ni, namely 4.26. Maximum CFs for Pb were lower than 1 in all species, except in *C. palustris*, where the concentration in the roots was occasionally similar to the sediment concentration.

Discussion

Aquatic plants in stormwater treatment ponds contribute to the reduction of hydraulic flow thus allowing greater residence time for sedimentation, filtration and bioaccumulation processes (Hares & Ward, 2004). Besides this, plant tissues (especially roots) contain an elevated concentration of nutrients and heavy metals, thus contributing to their elimination from the stormwater and accumulation in the pond, as shown in this study as well as reported by other authors (Scholes et *al*., 1998; Vardanyan & Ingole, 2006; Kadlec & Wallace, 2009).

Comparison of nutrient and metal concentration in different tissues of wetland plants showed that heavy metals and some of the macronutrients, like Fe, appeared in significantly higher concentrations in the roots as compared to the other plant tissues, which is consistent with other studies (Scholes et *al*., 1998; Ranieri, 2004; Vardanyan & Ingole, 2006; Sasmaz et *al*., 2008; Kadlec & Wallace 2009). Because heavy metals were not transported to the stems and leaves they do not present a threat for being consumed by herbivores and further accumulated along the food chain.

Restriction of metal translocation to the shoot is the strategy of metal tolerance for non-hyperaccumulators. With the restriction of metal translocation to the shoot, plants avoid the potential negative effects of high metal concentrations on the photosynthetic tissue. However, heavy metals and nutrients that are translocated to the shoot can be removed from the system through harvesting, thus reducing the accumulation of heavy metals in the system. The rationality of harvesting should be considered according to mass input of heavy metals and nutrients and the percentage removed by harvesting. Due to metal concentration in aboveground parts of wetland plants may vary during the growing season and may increase significantly at the end of growing season (Bragato et *al*., 2006), the timing of sampling and harvesting is of a big importance and should be included in the management plan of stormwater treatment systems.

P and K were in certain species accumulated in the shoots indicating an opportunity for nutrient elimination from a treatment system with harvesting. Elimination of nutrients by harvesting is more important in the case of low loads, where plant uptake can present a higher percentage of overall removal (Vymazal, 2004). Stormwater in this study had low P loads; consequently, plant harvesting could importantly contribute to P elimination from the systems.

In the investigated plant species, the average concentrations of heavy metals were mainly lower in the roots as compared to the sediment (CF < 1). The exception was Zn, which had the highest potential for phytostabilization using investigated wetland species. Lower heavy metals in the roots as compared to the sediment are in contrast to Cardwell et *al*. (2002), who investigated metal accumulation in different macrophytes from urban streams, and found that plant roots had higher metal concentrations than the adjacent sediments. However, in our study, there was a marked difference between the species. The results indicate that *I. pseudacorus* accumulates the lowest heavy metal concentrations in the roots. A part of the differences between the species might also be caused by different system loads, flow patterns and position of the species in the systems. Low uptake by *I. pseudacorus* was reported also by Ellis et *al*. (1994).

In our study, the highest heavy metal concentrations were accumulated in *R. hydrolapathum* followed by *P. australis*, however also *R. lingua* and *C. palustris* showed higher heavy metal concentrations compared to the other species.

Conclusions

- *Phragmites australis* and *Rumex hydrolapathum* are the most appropriate species for phytoremediation of stormwater due to heavy metal accumulation in the roots and high biomass. *Rumex hydrolapathum* accumulated the highest concentrations of heavy metals under the highest loads while accumulation was typically the lowest in *Iris pseudacorus*.
- There was no marked translocation of heavy metals into the aboveground tissues indicating no threat for accumulation of heavy metals along the food chain.
- P and K were often accumulated in the shoots; therefore the macrophyte harvesting can contribute to elimination of these nutrients from the system.

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References

APHA, 2005. Standard Methods for the Examination of Water and Wastewater, 21st Ed., Washington (DC), American Public Health Association (APHA), American Water Works Association (AWWA) & Water Environment Federation (WEF).

Bragato, C., Brix, H., Malagoni, M. 2006. Accumulation of nutrients and heavy metals in *Phragmites australis* (Cav.) Trin. Ex Steudel and *Bolboschoenus maritimus* (L.) Palla in a constructed wetland of the Venice lagoon watershed. Environmental Pollution 144: 967-975.

Bratieres, K., Fletcher, T.D., Deletic, A., Zinger, Y. 2008. Nutrient and sediment removal by stormwater biofilters: A large-scale design optimization study. Water Research 42: 3930-3940.

Brix, H. 1997. Do macrophytes play a role in constructed treatment wetlands? Water Science and Technology 35: 11-17.

Bulc, T., Vrhovsek, D. 2003. Highway runoff treatment in the city of Celje in Slovenia. Suvremeni promet 23: 79-83.

Cardwell, A.J., Hawker, D.W., Greenway, M. 2002. Metal accumulation in aquatic macrophytes from southeast Queensland, Australia. Chemosphere 48: 653-663.

Deutsch, J.C., 2003. Review of the Use of stormwater BMPs in EuropeProject under EU RTD 5th Framework Programme, Contract No EVK1-CT-2002-00111, Report 5.1., Adaptive Decision Support System (ADSS) for the Integration of Stormwater Source Control into Sustainable Urban Water Management Strategies. London, Middlesex University.
daywater.enpc.fr/www.daywater.org/REPORT/D5-1.pdf

Ellis, J.B., Revitt, D.M., Shutes, R.B.E., Langley, J.M. 1994. The performance of vegetated biofilters for highway runoff control. The Science of the Total Environment 146/147: 543-550.

Hares, R.J., Ward, N.I. 2004. Sediment accumulation in newly constructed vegetative treatment facilities along a new major road. Science of total environment 334-335: 473-479.

Hvitved-Jacobsen, T., Johansen, N.B., Yousef, Y.A. 1994. Treatment systems for urban and highway run-off in Denmark. The Science of Total Environment 146/147: 499-506.

Kadlec, R.H., Wallace, S.C. 2009. Treatment Wetlands. Second Edition. Boca Raton, CRC Press, Taylor & Francis Group: 1016 pp.

Pitt, R., Clark, S., Field, R. 1999. Groundwater contamination potential from stormwater infiltration practices. Urban water, 1: 217-236.

Ranieri, E. 2004. Chromium and Nickel removal in lab and pilot scale CW plants under different clogging conditions. 9th International Conference in Wetland Systems for Water Pollution Control, Avignon (France), 26-30 September 2004. Volume 2.

Sasmaz, A., Obek, E., Hasar, H. 2008. The accumulation of heavy metals in *Typha latifolia* L. Grown in a stream carrying secondary effluent. Ecological Engineering 33: 278-284.

Scholes, L., Shutes, R.B.E., Revitt, D.M., Forshaw, M., Purchase, D. 1998. The treatment of metals in urban runoff by constructed wetlands. The Science of the Total Environment 214: 211-219.

Somes, N.L.G., Fabian, J., Wong, T.H.F. 2000. Tracking pollutant detention in constructed stormwater wetlands. Urban Water 2: 29-37.

Vardanyan, L.G., Ingole, B.S. 2006. Studies on heavy metal accumulation in aquatic macrophytes from Sevan (Armenia) and Carambolim (India) lake systems. Environment International 32: 208-218.

Vollertsen, J. Lange, K.H., Pedersen, J., Hallager, P., Bruus, A., Laustsen, A., Bundesen, V.W., Brix, H., Nielsen, A., H., Nielsen, N.H., Wium-Andersen, T., Hvitved-Jacobsen, T. 2008. Removal of soluble and colloidal pollutants from stormwater in full-scale detention ponds. 11th International Conference on Urban Drainage, Edinburgh, Scotland, UN, 2008.

Vymazal, J. 2004. Removal of phosphorus via harvesting of emergent vegetation in constructed wetlands for wastewater treatment. 9th International Conference in Wetland Systems for Water Pollution Control, Avignon (France), 26-30 September 2004. Volume 2.