Acta Bot. Croat. 59(1), 215–223, 2000

CODEN: ABCRA 25
ISSN 0365–0588
UDC 556.55

Dedicated to Prof. dr. LJUDEVIT ILIJANIĆ on the occasion of his 70[th] birthday.

Nutrient removal from leachate of the Zagreb landfill Jakuševec

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Remediation of the City of Zagreb Jakuševec Dump Site, one of the largest dump sites in Europe, is in progress. Experimental laboratory results of leachate treatment using aquatic macrophytes show that increasing the concentration of ammonia in the leachate decreases elimination efficiency. In all series of experiments, significantly greater elimination of ammonia and orthophosphates has been obtained in planted than in unplanted mesocosms. For polishing the effluent from the pilot constructed wetland in the polishing pond the following species might be recommended: *Phragmites australis*, *Myriophyllum verticilatum*, *Ceratophyllum demersum*, *Lemna minor* and *Salvinia natans*.

Key words: leachate, mesocosms, *Phragmites australis*, aquatic macrophytes, nitrogen, phosphate.

Introduction

Jakuševec, the main, undeveloped and uncontrolled, refuse disposal site for the City of Zagreb, with a total current area of 80 ha, is one of the largest in Europe (PLETIKAPIĆ et al. 1996). It poses a health hazard for the inhabitants of the residential areas, and directly jeopardizes the existing and future potable water well fields in the City of Zagreb (EDWARDS et al. 1998, NIKOLIĆ and ŠVEL 1999). In 1995, the remediation of the Jakuševec Dump Site was initiated. So far, 12.5 ha have been turned into a landfill (NIKOLIĆ 1996, MILANOVIĆ et al. 1999).

To solve the problem of landfill leachate treatment, extensive technologies such as constructed wetlands and polishing ponds have been chosen, which provide simple and inexpensive leachate treatment (NIANG et al. 1996, BULC et al. 1997, SEKIRANDA and KIWANUKA 1998). The first model of constructed wetland in

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Croatia has been built to determine the capacity to purify leachate from the first section of the Jakuševec landfill, as well as its polishing in the polishing pond.

The objective of this study was to verify the treatment efficiency of aquatic macrophytes potted in experimental tanks and to simulate the processes in the future polishing pond system. The polishing pond at the Jakuševec landfill has been built to assess the efficiency of hydro–macrophytes in treating effluent from the pilot constructed wetland and to optimise designs for effective treatment.

Materials and methods

Experimental operation

Healthy plants of the common reed (*Phragmites australis* (Cav.)Trin ex Steudel) of a similar size were collected from a nearby natural habitat. Rhizomes with roots approximately 10 cm long were cut out and thoroughly washed with tap water. Cuttings of approximately 10 cm long of Eurasian water milfoil (*Myriophyllum verticillatum* L.) and coontail (*Ceratophyllum demersum* L.) as well as duckweed (*Lemna minor* L), salvinia (*Salvinia natans* (L.)All.) and water lettuce (*Pistia stratiotes* L.) were taken from the greenhouse of the Botanical Garden of the Faculty of Science, Zagreb. They too were thoroughly washed with tap water.

The experiments were carried out in 24 L glass aquariums, surface area 0.06 m^2 and depth of 0.4 m. Original surface gravel from the polishing pond was used as a 0.1 m deep substrate. Reactors were filled up with 10 L of the examined concentration of leachate (starting concentrations 1.0, 3.7, 7.3, 91.8 mg L^{-1} NH_3–N).

In each experimental reactor, 8 cuttings of *P. australis* were planted, and 5 cuttings of *Myriophyllum verticillatum* and *Ceratophyllum demersum*, 10 plants of *Pistia stratiotes*, 20 plants of *Salvinia natans* and 20 plants of Lemna minor.

Reactors with the substrate and the examined concentration of leachate but without the vegetation acted as a control.

The experiments were carried out with the natural day-night cycle and natural illumination from April to October 1998. The physical and chemical parameters of the water were measured for five days from the beginning of the experiments.

Nutrient analyses

Temperature and pH–value were taken with a WTW pH323 meter for temperature and pH measurement. Concentrations of ammonia (NH_3–N), nitrate (NO_3–N) and orthophosphate (PO_4^{3-}) in the water were measured colorimetrically on a DR/890 Hach colorimeter according to the standard methods for the examination of water and wastewater (APHA 1989). The samples were filtered before measurement through nitrocellulose filters, Sartorius pore size 0.2 µm. Concentrations of NH_3–N were determined by the salicylate method and of NO_3–N using the cadmium reduction method. Concentrations of PO_4^{3-} were determined as total reactive phosphorous by the ascorbic acid method.

Results and discussion

The temperature of the water during the experiment was maintained at 24±1 °C. pH in the experimental reactors ranged from 7.55 to 7.70, and in the control reactors from 8.0 to 8.15. The higher pH-value in the control reactors was probable due to higher concentrations of ammonia, the removal of which was less efficient in the control reactors.

Experimental laboratory results of the purification of the leachate using aquatic macrophytes show considerable differences in the purification efficiency of the experimental and the control reactors and also in different starting concentrations of ammonia (Tab. 1).

Tab. 1. Mean initial nutrient concentrations and percentage of removal in mesocosms after a 120 h experiment.

Series	NH_3–N		NO_3–N		PO_4^{3-}	
	initial conc.	removal (%)	initial conc.	removal (%)	initial conc.	removal (%)
experiment 1	1.0	94.2	5.4	7.2	0.30	52.2
control 1	1.6	31.9	6.3	9.7	0.33	43.2
experiment 2	3.7	91.1	2.8	35.7	0.45	62.1
control 2	4.3	21.6	1.0	46.5	0.26	47.8
experiment 3	7.3	46.7	1.4	–95.6	0.29	43.0
control 3	6.5	–48.6	3.0	73.2	0.23	36.5
experiment 4	91.8	50.4	15.3	–128.7	0.40	58.1
control 4	80.4	24.4	8.8	–24.1	0.35	39.0

Results show increasing the concentration of ammonia in the leachate decreases the efficiency with which it is eliminated (Figs. 1, 2, 3, 4). In all series of experiments, significantly (Students t-test, $p < 0.05$) greater elimination of ammonia was found in planted than in unplanted mesocosms.

In all the series of experiments, greater elimination of orthophosphates has been achieved in the planted than in the unplanted mesocosms (Figs. 1, 2, 3, 4). In series 1 and 2 significantly (Students t-test, $p < 0.05$) greater elimination of orthophosphates has been obtained in planted than in unplanted mesocosms. There were no significant differences among the mesocosms in series 3. In series 4 planted and unplanted mesocosms differed significantly at the level of $p < 0.001$. Better nitrogen and phosphorous removal from wastewater in planted reactors than in unplanted reactors has been also previously reported by other authors (Brix 1994, 1997, Zhu and Sikora 1995, Pelton et al. 1998, Sekiranda and Kiwanuka 1998).

Figure 5 shows the results of cluster analysis applied to the data of ammonia removal efficiency in experimental and control reactors. The dendrogram displays three main clusters. The ammonia removal efficiency in experimental series 1 and 2 was not similar to that in experimental series 3 and 4, which are more similar to those of control series 1, 2 and 4. Control series 3 is considerably dif-

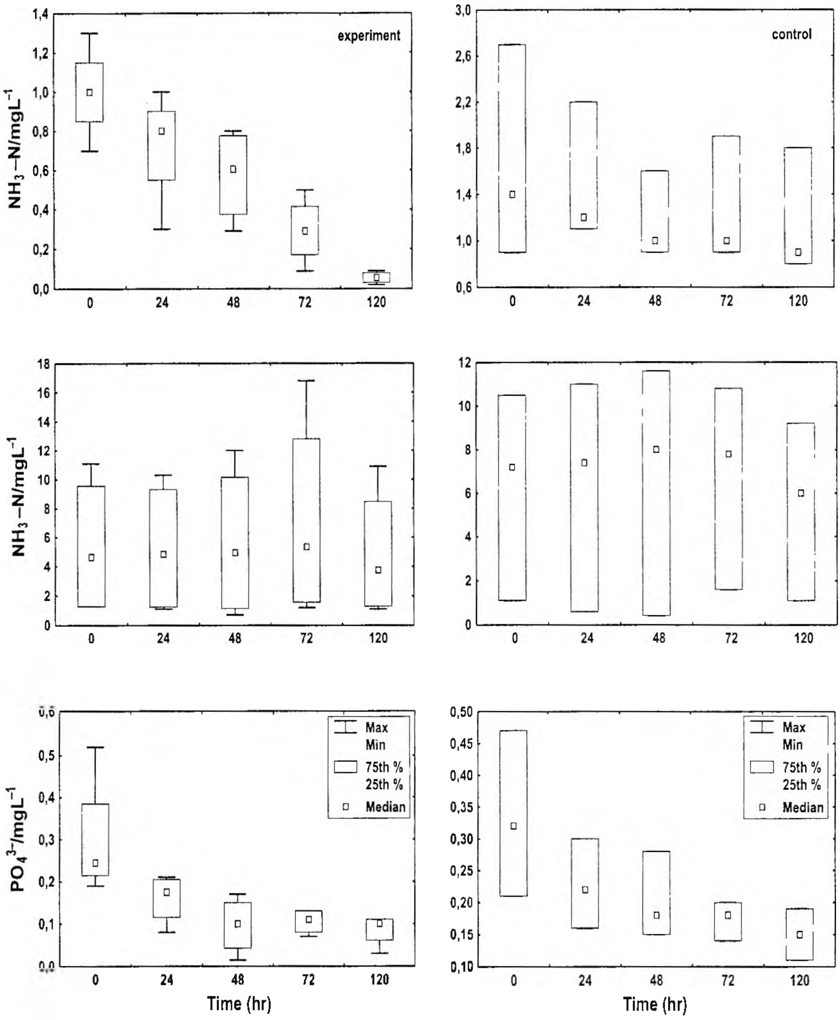

Fig. 1. Box–whisker plots for experimental and control reactor treatment performance relative to the influent concentrations for: NH_3–N, NO_3–N and PO_4^{3-}. Mean influent concentrations in experimental reactors (n=5): NH_3–N 1.0 ± 0.2 mg L^{-1}, PO_4^{3-} 0.30 ± 0.15 mg L^{-1}, and in control reactors (n=3): NH_3–N 1.6 ± 0.9 mg L^{-1}, PO_4^{3-} 0.33 ± 0.13 mg L^{-1}.

ferent to the other series. Figure 6 shows the results of cluster analysis applied to the data of removal efficiency of orthophosphates in the experimental and control reactors. The dendrogram displays two main clusters. Orthophosphate removal efficiency in experimental series 1 and 2 was similar to that in experimental series 4 and control series 1. Experimental series 3 is closer to control series 2, 3 and 4 than to the other experimental series.

These results confirmed that nutrients were more effectively removed from leachate in planted mescosms with lower initial ammonia concentrations. Acor-

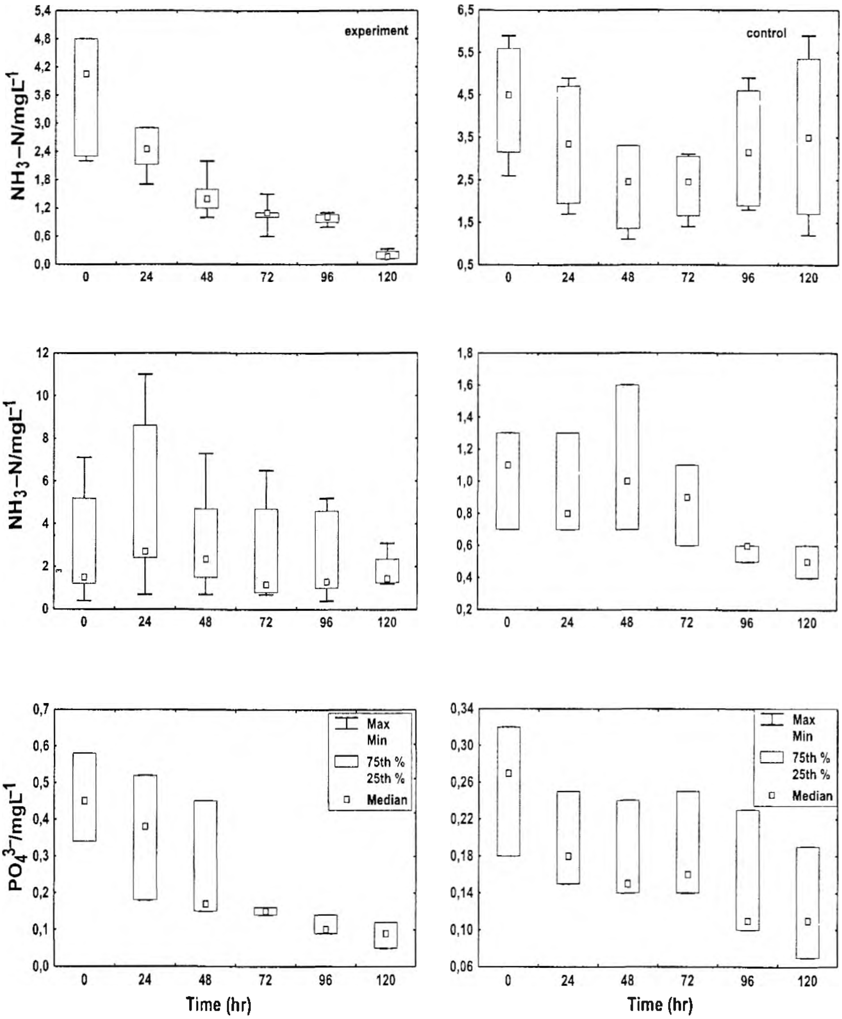

Fig. 2. Box–whisker plots for experimental reactor treatment performance relative to the influent concentrations for: NH_3–N, NO_3–N and PO_4^{3-}. Mean influent concentrations in experimental reactors (n=8): NH_3–N 3.7 ± 1.1 mg L^{-1}, PO_4^{3-} 0.45 ± 0.12 mg L^{-1}, and in control reactors (n=4): NH_3–N 4.3 ± 1.5 mg L^{-1}, PO_4^{3-} 0.26 ± 0.07 mg L^{-1}.

ding to SEKIRANDA and KIWANUKA (1998), the most probable mechanisms for the removal of nutrients in unplanted mesocosms are adsorption in substrate and immobilisation by micro–organisms and the phytoplankton component.

The results confirmed the effectiveness of the purification of leachate from Zagrebs landfill Jakuševec using aquatic macrophytes in the polishing pond. For treatment of the effluent from the pilot constructed wetland in the polishing pond the following species can be recommended: *Phragmites australis*, *Myriophyllum verticilatum*, *Ceratophyllum demersum*, *Lemna minor* and *Salvinia natans*.

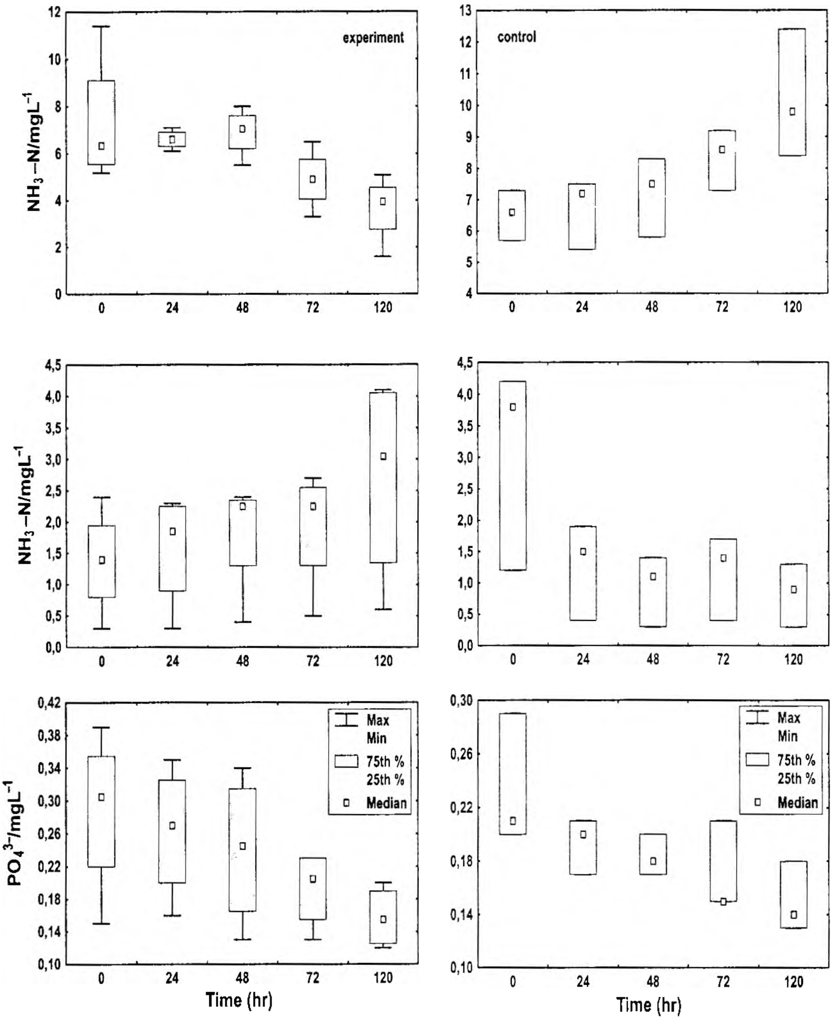

Fig. 3. Box–whisker plots for experimental reactor treatment performance relative to the influent concentrations for: NH_3–N, NO_3–N and PO_4^{3-}. Mean influent concentrations in experimental reactors (n=5): NH_3–N 7.3 ± 2.8 mg L^{-1}, PO_4^{3-} 0.29 ± 0.10 mg L^{-1}, and in control reactors (n=3): NH_3–N 6.5 ± 0.8 mg L^{-1}, PO_4^{3-} 0.23 ± 0.05 mg L^{-1}.

Pistia stratiotes displayed symptoms of chlorosis during the experiment. Moreover, it appears incapable of sustaining lower temperatures so we do not recommend it be used for treatment in the polishing pond. According to the experimental laboratory results of the purification of leachate using aquatic macrophytes, the hydraulic retention time in the polishing pond of five days and an initial load up to 10 mg/L NH_3 can be recommended. These results agree with BODE et al. (1998), where a hydraulic retention time in the polishing pond of 1–5 days is recommended.

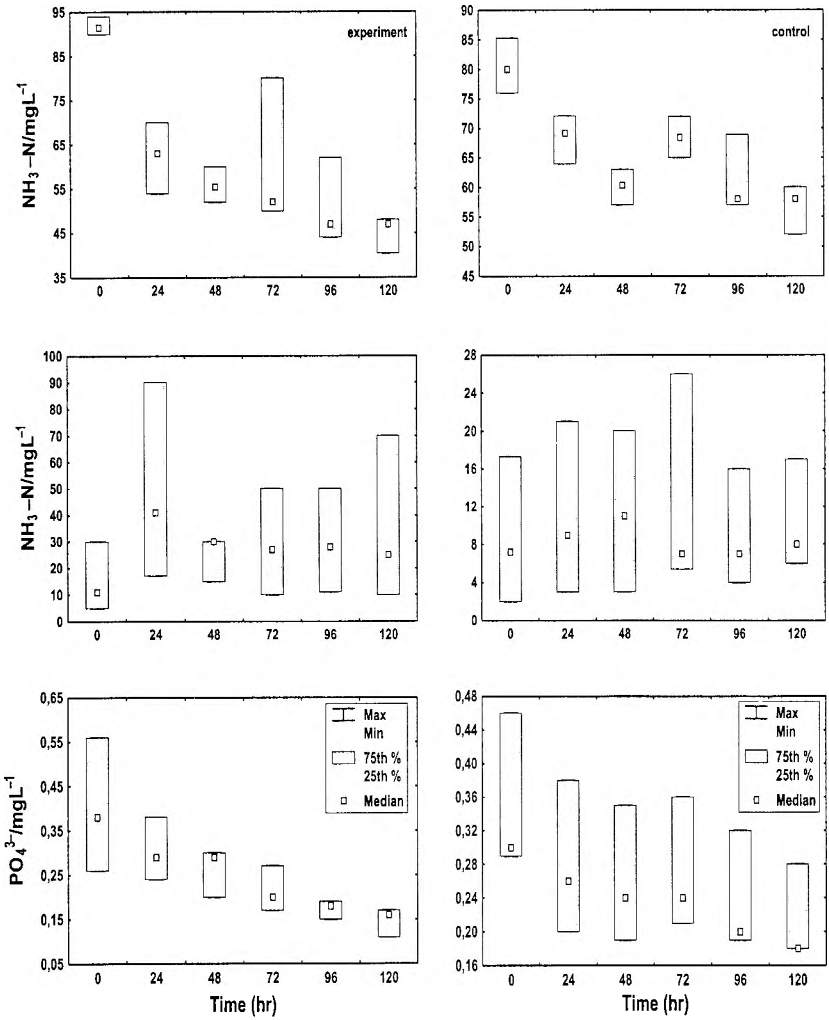

Fig. 4. Box–whisker plots for experimental reactor treatment performance relative to the influent concentrations for: NH_3–N, NO_3–N and PO_4^{3-}. Mean influent concentrations in experimental reactors (n=5): NH_3–N 91.8 ± 2.1 mg L^{-1}, PO_4^{3-} 0.40 ± 0.15 mg L^{-1}, and in control reactors (n=3): NH_3–N 80.4 ± 4.7 mg L^{-1}, PO_4^{3-} 0.35 ± 0.10 mg L^{-1}.

Conclusions

The purification of leachate using aquatic macrophytes in mesocosms shows that increasing the concentration of ammonia in leachate decreases the efficiency the efficiency with which it is eliminated. In all series of experiments, significantly greater elimination of ammonia and orthophosphates has been obtained in planted than in unplanted mesocosms. For the polishing of the effluent from a pilot constructed wetland in the polishing pond the following species can be recommended: *Phragmites australis, Myriophyllum verticilatum, Ceratophyllum*

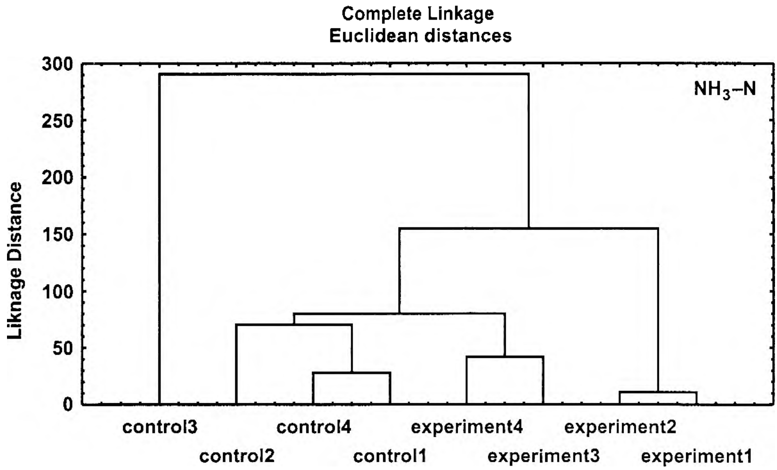

Fig. 5. Dendrogram showing the results of cluster analysis for series of experimental and control reactors relative to the purification efficiency of NH_3–N after a 120 h experiment.

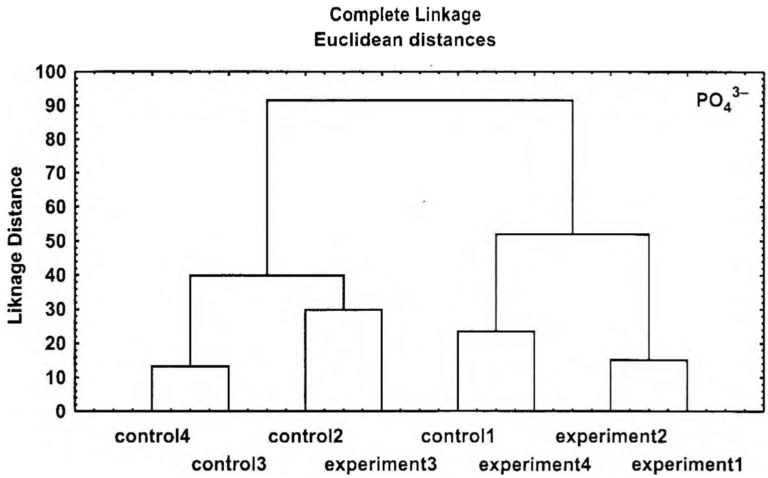

Fig. 6. Dendrogram showing the results of cluster analysis for series of experimental and control reactors relative to the purification efficiency of PO_4^{3-} after a 120 h experiment.

demersum, *Lemna minor* and *Salvinia natans*. A hydraulic retention time in the polishing pond of five days and an initial load of up to 10 mg/L NH_3 can be recommended.

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