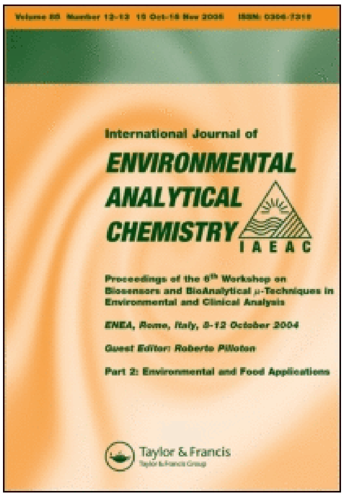

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Pesticide retention in two small constructed wetlands: treating non-point source pollution from agriculture runoff

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Pesticide losses to the environment are undesirable because of possible environmental hazards. Loss of pesticides is likely in watersheds where pesticides are used. Small constructed wetlands (CWs) in first- and second-order streams can reduce the loss of pesticides, since water-purification processes are stimulated. Four herbicides and three fungicides were applied on arable soil on two watersheds in Norway. The two CWs are situated in western and eastern Norway. The CWs cover 0.15% and 0.4% of the watershed, respectively. This study presents the pesticide retention obtained in the two CWs. All applied pesticides were found in the streams, with the highest concentrations being found immediately after spraying. The pesticides added to the watersheds decreased on average, through the whole sampling periods, from 3 to 67%. The retention increased with the size of the wetland. In many cases, the CWs reduced the peak concentrations to values regarded as non-toxic for aquatic life.

Keywords: Constructed wetland; Fungicide; Herbicide; Non-point source/diffuse pollution

1. Introduction

Monitoring of river water and groundwater in Norway has revealed pesticide residues from 36 compounds in 63% of the samples [1, 2]. Even though concentrations are often low, further reductions in pesticide levels in runoff are desirable for both environmental and health reasons.

Several processes influence the reduction in pesticides in rivers, creeks, lakes, and ponds: sedimentation, uptake and adsorption to organisms, biological degradation, photo degradation, diffusion, and dilution [3, 4]. However, several pesticides resist degradation, e.g. DDT, HCH, aldrin, bentazone, and atrazine [5]. Important factors influencing degradation in water courses are compound formulation, product additives, local climate (water temperature, precipitation, and hydrology), water chemistry, and biology. Degradation is generally faster in surface water than in groundwater, mainly because of the higher biological activity and exposure to sunlight.

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Because of Norway's rugged topography, CWs are often only 0.03–0.4% of the watershed area. Previous research, however, has shown that these small constructed wetlands are capable of retaining suspended solids and particle-bound nutrients [6, 7]. The small CWs were less effective in reducing the content of dissolved phosphorus (P) and nitrogen (N). Wetland degradation of herbicides such as mecoprop and atrazine has been reported to be 36 and 100%, respectively [8, 9]. High retention rates have also been reported for azinphos-methyl, chlorpyrifos, and endosulphan [10], but the retention time there was much longer than in a typical Norwegian CW.

This study presents the results from studies of pesticide runoff from two arable fields entering the CWs: 'Lier' and 'Grautholen'. The main objective was to investigate whether small wetlands with relatively high hydraulic loads are capable of reducing pesticide contents in arable streams.

2. Experimental

2.1 *Site description*

2.1.1. Grautholen. The 0.22 km^2 watershed is located about 45 km south of Stavanger in south-western Norway. The constructed wetland Grautholen was built in 1993 by expanding the stream banks (figure 1). The constructed wetland is 100 m long and has a surface area of 840 m^2.

Depths at low water flow were originally 1 m in a, 0.5 m in b, 0 m in c and 0.5–0.8 m in d. However, the wetland has become shallower as a result of sedimentation. Thus, depths were approximately 0.5 m in a, 0–0.3 m in b, 0 m in c, and 0–0.3 m in d from May 2000 to December 2001. Sediments were high in organic content (18–37% as loss of ignition).

The entire wetland was covered with vegetation, mainly *Sparganium erectum* L. (exotic burreed), *Phragmites australis* (Cav.) Trin. ex Steud. (common reed), and *Phalaris arundinacea* L. (reed canary grass) in the wetland filters. In the overflow zones, *S. erectum*, *Myostis scorpioides* L. (water forget-me-not), *Urtica dioica* L. (common nettle), and various grasses dominated. The vegetation cover always exceeded 70%.

2.1.2. Lier. Lier is located 40 km south of Oslo in the eastern part of Norway. The wetland is about 1200 m^2 and receives water from a 0.8 km^2 large catchment area. The constructed wetland Lier was built in 2001.

This paper presents the results of measurements in samples collected between the sedimentation pond (LIT) and the outlet (LO) (figure 2). Water entering from

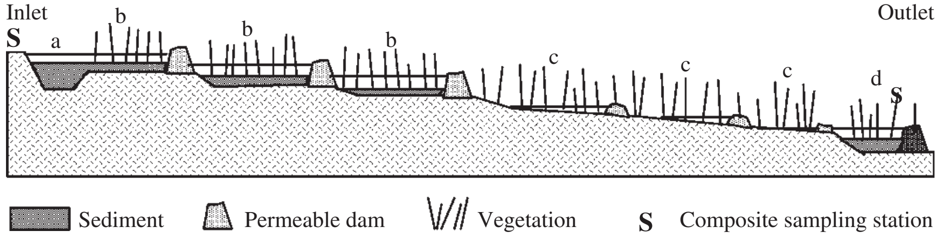

Figure 1. Constructed wetland Grautholen: (a) sedimentation pond, (b) wetland filter, (c) overflow zone covered with vegetation, and (d) outlet basin with a V-notch.

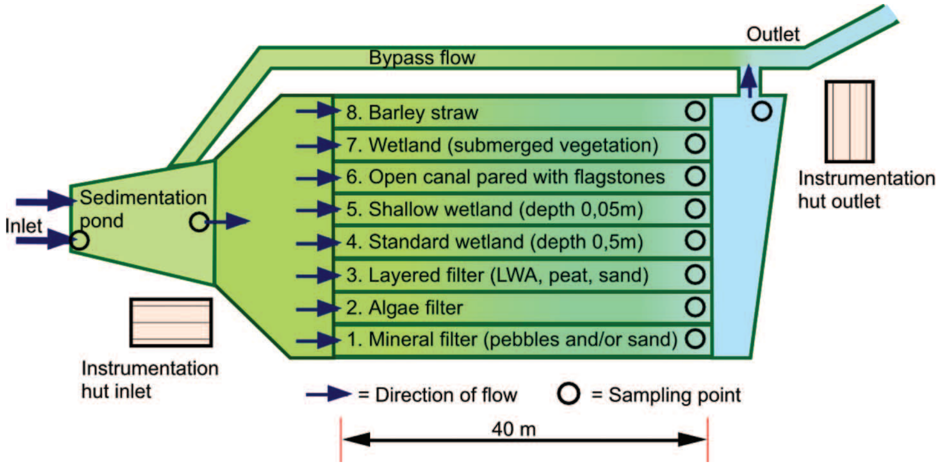

Figure 2. Constructed wetland in Lier. CW Lier is built as an experimental wetland with eight different types of filters.

the sedimentation pond is distributed through a constructed vegetation filter into eight parallel wetland compartments. Each is approximately 3 m wide and 40 m long. Each compartment has an individual V-notch in the inlet to secure the same input of water to all compartments. Figure 2 shows the content of each of the eight filters. Downstream of the sedimentation pond, there is a bypass possibility in cases of high-flow situations. Water from each compartment flows to a collecting wetland and leaves the test wetland through a shallow outlet dam. As figure 2 shows, all the filters, except compartments 2 and 7, are covered with wetland vegetation, mainly *Phalaris arundinacea* L. (reed canary grass), *Glyceria fluitans* L, *Typha latifolia* L. (cattail), *Sparganium erectum* L. (exotic bur reed), and *Phragmites australis* (Cav.) Trin. ex Steud. (common reed).

2.2 *Pesticide application*

Previous research [6, 7] has shown that the retention of soil particles, phosphorus, and nitrogen in constructed wetlands is affected by factors in the watershed, e.g. agricultural production, soil texture, and aggregate stability. In order to study the natural pesticide transport in these filters, the pesticides were applied in the watershed. Hence, natural processes like precipitation, adsorption, and degradation could affect the pesticides. The applied pesticides are presented in table 1.

These pesticides were chosen for a number of reasons. They are frequently detected in agricultural surface water runoff in Norway [2]; they represent normal use in agricultural areas with high pesticide runoff; they represent a relatively wide range of properties in terms of water solubility and soil- and organic adsorption (table 1); and they are analysed using the same methods.

Most of the pesticides were added once a year, in Grautholen, at the end of May 2000 and 2001. Metribuzin, however, was added only in 2000, while propiconazole and fenpropimorph were added twice per season, with additional spraying in mid-July. In Lier, the pesticides were added in late June 2003. High doses of pesticides were

Table 1. Information on the compounds[a].

Pesticide	Chemical	Type	K_{ow} (log)	K_{oc} (log)	Water sol. (mg/L)	$T_{1/2}$ (days)	Vapour pressure (mPa)
Fenpropimorph	Morpholine	F	2.6	3.43	4.3	60	2.30
Linuron	Urea	H	3	2.7	75	82	0.19
Metalaxyl	Acylalanine	F	1.75	2.23	8400	80	0.75
Metamitron	1,2,4-Triazinone	H	0.83	0.85	1700	30	Low
Metribuzin	1,2,4-Triazinone	H	1.58	1.72	1000	47	0.02
Propachlor	Chloroacetanilide	H	2	1.9	613	12	30.60
Propiconazole	Azole	F	2.8	2.8	100	53a/>83 an	0.06

[a]F: fungicide; H: herbicide; K_{ow}: lipofilicity; K_{oc}: soil adsorption; Water sol.: water solubility (at pH: 7 if not stated otherwise); $T_{1/2}$: soil or water half-life; a: aerobic; an: anaerobic.

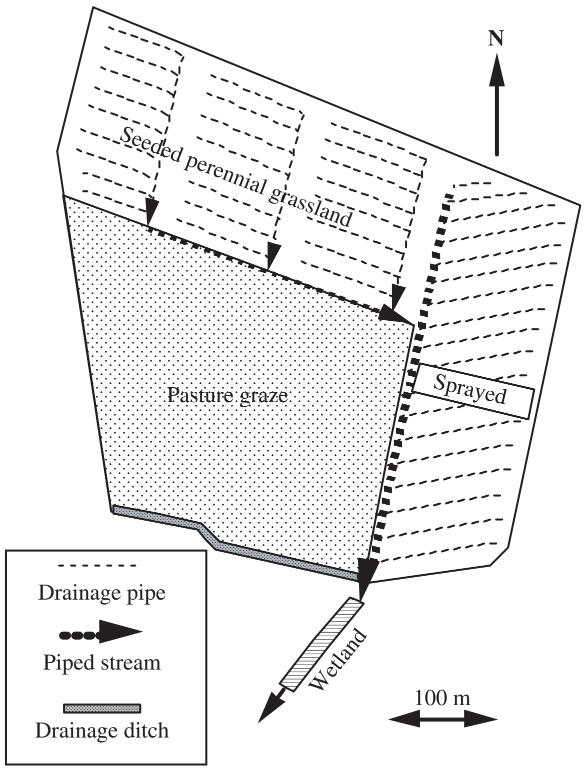

Figure 3. High doses of pesticides were sprayed on an upstream area (0.1–0.2 ha) near the CWs.

sprayed on an upstream area (0.1–0.2 ha) near the CWs. Figure 3 gives an example of the sprayed area in Grautholen.

2.3 *Water-flow measurements and composite sampling*

Water flow was monitored in V-notches in the inlet (Lier) and outlet (Grautholen). A logger connected to a pressure gauge recorded the discharge and controlled a *water flow proportional sampling system* in the inlet and the outlet. Sub-samples were collected daily and pumped through plastic hose into plastic sample containers (Grautholen) and through copper pipes into copper containers (Lier). Containers were placed in fridges. On average, 12–16 sub-samples were collected daily from the inlet and the outlet. A 1 L sample was taken from the sample container, usually at 10- to 14-day intervals. Heating cables prevented pumps and tubes from freezing and enabled sampling throughout the entire year.

2.4 *Sampling and analysis*

Samples were collected and analysed frequently from mid-May to September (the summer months in Norway). During autumn and winter, approximately one composite sample per month was analysed in Grautholen and two composite samples per month was analysed in Lier. Pesticides were preserved in the field by adding 25 mL of dichloromethane (DCM) to 500 mL of water in a glass bottle and stored at 4°C until analysis by GC with NP-EC [11]. The samples were delivered for continuous analysis a short time after they were collected.

3. Results and discussion

3.1 *Hydraulic load*

The hydraulic loading rate (HLR) is runoff (m^3/day) divided by wetland surface area (m^2). Usually, retention increases as the HLR decreases because of a longer detention time.

3.1.1. Grautholen. The average HLR for the 19 month period was 1.8 m day^{-1}. For our period of investigation (May to September), the HLR was 0.5 and 0.4 m day^{-1} for 2000 and 2001, respectively (figure 4). The runoff was characterized by larger single runoff events in the first year than in the second.

3.1.2. Lier. The average HLR from May to September 2003 was 0.9 m day^{-1}. Figure 5 shows the hydraulic load, with peaks in May and July. The HLR was higher in Lier compared with Grautholen, as expected, because the surface area in Grautholen is larger than in Lier.

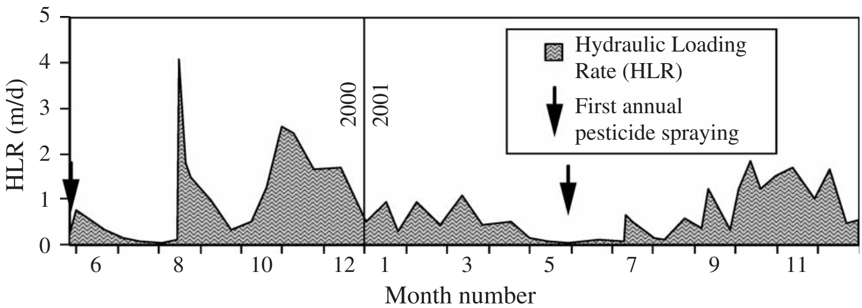

Figure 4. Hydraulic load in the constructed wetland Grautholen throughout the period of investigation.

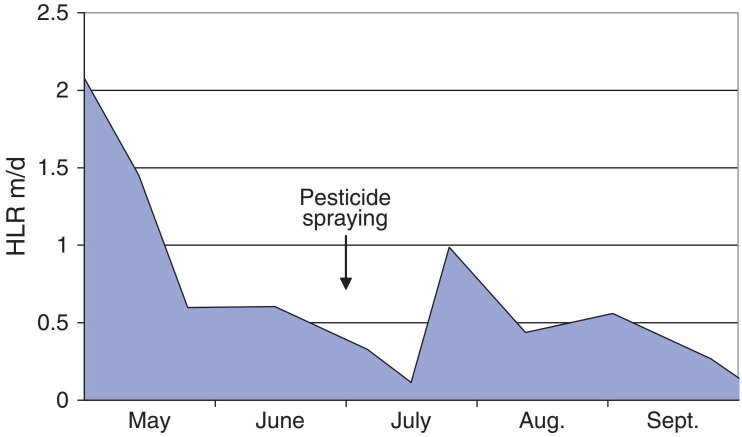

Figure 5. Hydraulic load in the constructed wetland Lier throughout the period of investigation.

Table 2. Measured input of pesticides and retention percent in Grautholen (May to September 2000 and 2001) and Lier (May to September 2003) and the average percentage retention in both of the constructed wetlands.

	Grautholen 2000		Grautholen 2001		Lier (2003)	
	Input (g)	Ret. (%)	Input (g)	Ret. (%)	Input (g)	Ret. (%)
Propachlor	60.0	67	3.5	14	10.8	47
Metribuzin[a]	28.2	40	0.2	19	1.9	3
Linuron	22.9	30	7.2	3	16.1	19
Metamitron	124.4	58	2.8	7	4.1	11
Metalaxyl	140.9	41	6.5	−11[b]	3.8	3
Propiconazole[c,d]	11.0	25	13.2	13		
Fenpropimorph[c]	4.9	36	5.1	10	1.0	15
Air temperature (°C)	12.5		12.8		14.0	

[a]Metribuzin has been applied only one yaer (2000) in Grautholen. [b]Metalaxyl was one of three compounds with residues in the soil. It may have been washed out from the previous year's application. Metalaxyl has a very long half-life in soil, but a high water solubility. [c]Propiconazole and fenpropimorph were added twice per season in Grautholen. [d]Propiconazole was measured only at 'Grautholen'.

3.2 *Pesticide retention*

Arable soils have a considerable capacity for retention of pesticides [12]. The pesticide concentrations in the inlet indicate that only a small percentage of the applied pesticides leached from the watershed; still, all the added pesticides were found in both the CWs. Table 2 gives a summary of the measured input of pesticides and the relative retention percentage in the CWs in Grautholen (two seasons) and Lier (one season). The amount of pesticides removed in the CWs varied from 3 to 67% (table 2). The percentage pesticide reduction increased with higher concentrations of pesticides.

Propachlor, metribuzin, linuron, metamitron, metalaxyl, and fenpropimorph were added to both Grautholen and Lier. Also, propiconazole was added to Grautholen. Note that the amount pesticide applied to the catchments was approximately the same each year. The loss from the catchments in Grautholen varied, however, from one year to another (table 2). The number of days between spraying and precipitation was important for the loss of pesticide. This explained a much higher loss from Grautholen in 2000 compared with 2001 (compare table 2 with the hydraulic loading rate in figure 5). Detailed results from Grautholen are in Braskerud and Haarstad [12].

4. Conclusion

Only a few percent of the applied pesticides were leached from the watershed; yet, they produced concentration peaks that can be harmful for aquatic life. The average compound retention varied from 3–67%. Results show that the input and retention are correlated with the hydraulic loading rate. The two constructed wetlands in Norway reduced the peak concentration of pesticide to levels which are less harmful to aquatic life. This is encouraging in view of the relatively small size of the wetland systems. However, wetland technology does not automatically allow for less restrictive use of pesticides in the agricultural practice. Further research is needed in this area. At present, an interesting study is being carried out, where the main objective is to compare the pesticide retention in eight wetland compartments in 'Lier' (figure 2). The results will provide information about how different systems affect the retention processes of different compounds. We are also planning to develop a mathematical model for the fate of pesticides in constructed wetlands.

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