Control of nuisance chironomid midge swarms from a slow sand filter

A. J. Peters, P. D. Armitage, S. J. Everett and W. A. House

ABSTRACT

The pyrethroid insecticide permethrin was evaluated for controlling the emergence of chironomid midges from slow sand filter beds. The hydrodynamics of the slow sand filter were studied using a chemical tracer, and mesocosm experiments were undertaken to examine the effects of permethrin on the filter bed micro-fauna community. A single treatment dose of 96 μg/l permethrin was applied to a slow sand filter. Permethrin rapidly dispersed in the water and accumulated in the surface layer (the 'schmutzdecke') of the filter, attaining mean maximum average concentrations of 8.3 μg/l in water and 2.3 μg/g in the schmutzdecke after 1 and 6 h, respectively. Concentrations then rapidly decreased to below detection limits after 7 days in water and 48 h in the schmutzdecke. After 28 days the filter bed was drained and core samples were retrieved for analysis of permethrin. Permethrin was not detected in the out-flowing water at any time or in any of the filter bed core samples. These data suggest that all the permethrin was adsorbed and/or degraded in the water column and schmutzdecke. The single treatment was effective in eliminating chironomid midge emergences from the filter bed for a period of 1 month. Furthermore, there were no apparent adverse effects on other major components of the filter bed micro-fauna community.

Key words | chironomid midges, permethrin, schmutzdecke, slow sand filter, water

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INTRODUCTION

Slow sand filter beds are commonly used in the production of drinking water. Typically, a slow sand filter consists of a large tank containing a layer of sand, often interspersed with a layer of granular activated carbon (GAC), in which case the construction type is termed a GAC Sandwich™. This is overlain by a constant head of water which percolates down through the filter bed and out of a porous base from where it is collected and subjected to chemical disinfection. Suspended particulate and colloidal matter in the inflowing water is deposited and adsorbed on the surface of the sand, stimulating the development of a surface layer termed the 'schmutzdecke'. This is a complex nutrient and organic rich layer which is rapidly colonised by a range of diatoms, filamentous algae and an associated invertebrate and microbiological community (Rachwal et al. 1996).

Slow sand filters thus make ideal habitats for chironomid midges to breed in. Adult chironomids are generally short-lived (a few days), during which time their eggs are laid in water and then typically hatch in 2–4 days. The larvae grow rapidly, living in the schmutzdecke and feeding on the supply of nutrients filtered out by the sand bed. Densities of $2.5 \times 10^5\ m^{-2}$ can be attained (Armitage 1995). In the spring, when the water temperature increases, large numbers of adults emerge and the males form airborne swarms which the females enter to mate, and the life-cycle is repeated. The swarms formed on emergence can cause severe nuisance to humans, particularly when they occur in suburban and urban areas where they can cause, for example, damage to furnishings and painted surfaces, physical discomfort and reduction in visibility leading to interference with transport (Ali 1995). In

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addition, although they are non-biting, there is some evidence that the haemoglobin from chironomid midges can induce an allergic response in some people (Cranston 1995).

This project was instigated to assess the efficacy and feasibility of using permethrin, a pyrethroid insecticide, to control the emergence of midges from slow sand filter beds of the GAC sandwich™ design at a water treatment plant in southern England by eliminating chironomid larvae in the schmutzdecke.

Permethrin is a non-systemic, contact insecticide, used to control a broad range of insect pests in agricultural, horticultural, and veterinary and human medicinal applications (BCPC 1997). Permethrin, in the formulation 'PermasectWT', is registered by the United Kingdom Drinking Water Inspectorate (DWI) for use under licence as a disinfestation product in water supply systems (DWI 2000). PermasectWT is a 2% w/v solution of permethrin in absolute alcohol (ethanol). Laboratory testing of the toxicity of permethrin to a wide range of aquatic invertebrate species has been conducted (e.g. Mokry & Hoagland 1990; Parsons & Sturgeoner 1991; Tang & Siegfried 1996), in addition to field based studies (e.g. Yasuno *et al*. 1988; Werner & Hilgert 1992). Reviews of the aquatic ecotoxicology of permethrin have been compiled by Hill (1989) and Mian & Mulla (1992).

Permethrin is strongly hydrophobic and lipophilic (BCPC 1997; Mackay *et al*. 1997). It is predicted that permethrin added to the inflowing water of a slow sand filter will rapidly partition between the water and solid phases of the filter system, as has been observed in test ponds (Conrad *et al*. 1999). The permethrin should accumulate in the schmutzdecke layer on the surface of the filter bed as this has a high organic matter content, for which permethrin has a high sorptive affinity, as indicated by its relatively high organic carbon normalised partition coefficient ($\log K_{oc} = 4.8$) (Mackay *et al*. 1997). Any permethrin remaining in solution which passes through the schmutzdecke, should be removed by adsorption to the GAC layer of the filter bed. This should therefore ensure that the EU Drinking Water Directive limit of 0.1 μg/l is not exceeded and consumer safety is thereby ensured.

Owing to the high degree of microbiological activity typically present in slow sand filter beds (Eighmy *et al*. 1992), it can be expected that permethrin will undergo rapid biotic degradation, assuming that the microbiological viability of the filter bed is not diminished by any effects of the permethrin. Evidence suggests that pyrethroid insecticides are not toxic to soil microorganisms (Hill 1989) or to anaerobic bacteria present in a waste treatment bioreactor (Cohen 1992), and so it can be expected that the microbiological community of the schmutzdecke will also not be adversely affected by permethrin.

METHODS AND RESULTS

The study consisted of three distinct phases: (1) investigation of the water flow characteristics and residence time in the filter bed components; (2) determination of the toxicity of permethrin to chironomid midge larvae in the schmutzdecke, and also to the associated micro- and macro-fauna; (3) treatment of the filter with permethrin and monitoring of its effects. These are detailed in sequence below.

Filter bed flow characteristics

Prior to treatment with permethrin, the flow characteristics of the filter bed needed to be established to aid in determining an efficient application method for the permethrin. The residence time of the water also needed to be determined as this would in part determine the effective duration of treatment with a single dose. Table 1 gives the filter bed characteristics.

Lithium was chosen as a tracer as it is registered for use as such in drinking water supply systems (DWI 2000) and is easily analysed. Lithium chloride (15 kg) was dissolved in distilled water and added to the inflow water as a single pulse at time $(t) = 0$. Water samples were collected at 15 min intervals, starting at $t = -15$, from each of 7 stations around the filter bed (see Figure 1). These were taken at depths of 10 and 53 cm to monitor surface and bottom water, respectively (the bottom water sample was

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Table 1 | Filter bed characteristics

Filter bed dimensions (length × width)	55 × 30 m
Water depth	0.63 m
Overlying water volume	1040 m^3
Filter composition:	
Top sand layer	0.40 m
GAC layer	0.07 m
Bottom sand layer	0.29 m
Filter volume	1255 m^3
Filter water content at 45% porosity	565 m^3
Total water volume	1605 m^3
Volumetric flow rate	32 Ml/week (53 l/sec)

collected at 10 cm above the filter bed surface). An automated programmable sampler was deployed at the outflow to determine filter bed breakthrough. These samples were collected at 15 min intervals to coincide with the manual sample collections, and then collected at 20 min intervals to monitor the following 8 h (46 samples in total). All samples were analysed for lithium by ion chromatography (Jarvie *et al.* 1997) and the results are shown in Figure 1.

A theoretical residence time of water, T_w, is calculated from:

$$T_w = V/Q \quad (1)$$

where V = total volume (1.605×10^6 l), Q = volumetric flow rate (53 l/s) and hence: $T_w = 30{,}283$ s = 8.4 h. This represents the average time taken for water to pass through the entire filter bed. Using only the volume of overlying water (1,040 m^3) gives a value of 5.5 h, which represents the average transport time for inflowing water to travel to the surface of the filter bed.

The key findings from the lithium tracer experiment show that the water appears to be well mixed vertically: there is no appreciable time delay in bottom water concentration levels compared to surface water concentrations. Also, the water is well mixed horizontally, with all sites exhibiting elevated lithium concentrations within 80 min. The residence time of water in the filter bed is approximately 8.9 h, as indicated by peak concentrations in outflow. This compares well with the theoretical value of 8.4 h calculated above. Extrapolation of the outflow curve indicates that complete turnover of the water in the filter bed should be complete in approximately 25 h.

The implication of these results for treatment with permethrin are: (i) inflowing water mixes rapidly in the filter, thus suggesting that permethrin added to the inflowing water will be efficiently mixed throughout; (ii) permethrin which is dosed at the surface of the water and remains in solution can be expected to reach the surface of the filter bed (and therefore reach the chironomid larvae) within 80 min; (iii) the majority of dissolved permethrin will have reached the surface of the SSF after 9 h, and all permethrin should be removed from the water and adsorbed on the schmutzdecke and/or the sand/GAC after 25 h; (iv) any permethrin which remains in solution and is not retained by any of the filter components will exit the system within a maximum time of 25 h, with the majority doing so within the first 12 h.

Mesocosm experiments

The toxicity of permethrin to the entire schmutzdecke micro- and macro-invertebrate community was tested using mesocosms. While not exactly replicating filter bed conditions (e.g. static, not flowing water), they provided information on the response to permethrin of the whole community over time.

Schmutzdecke and its associated fauna (see Table 2 for invertebrate components) was collected from the filter bed and aliquots placed in 150 ml mesocosm vessels with filter bed water, to give approximately a 1–2 cm depth of substratum overlain with 100 ml of water. The vessels were aerated using aquarium pumps and maintained at a temperature ranging from 18 to 22°C. They were dosed with PermasectWT (Mitchell Cotts Chemicals, Mirfield) to achieve initial nominal water concentrations of permethrin at 1, 5, 10, 20 and 100 μg/l. Each dose level was replicated three times and corresponding controls were

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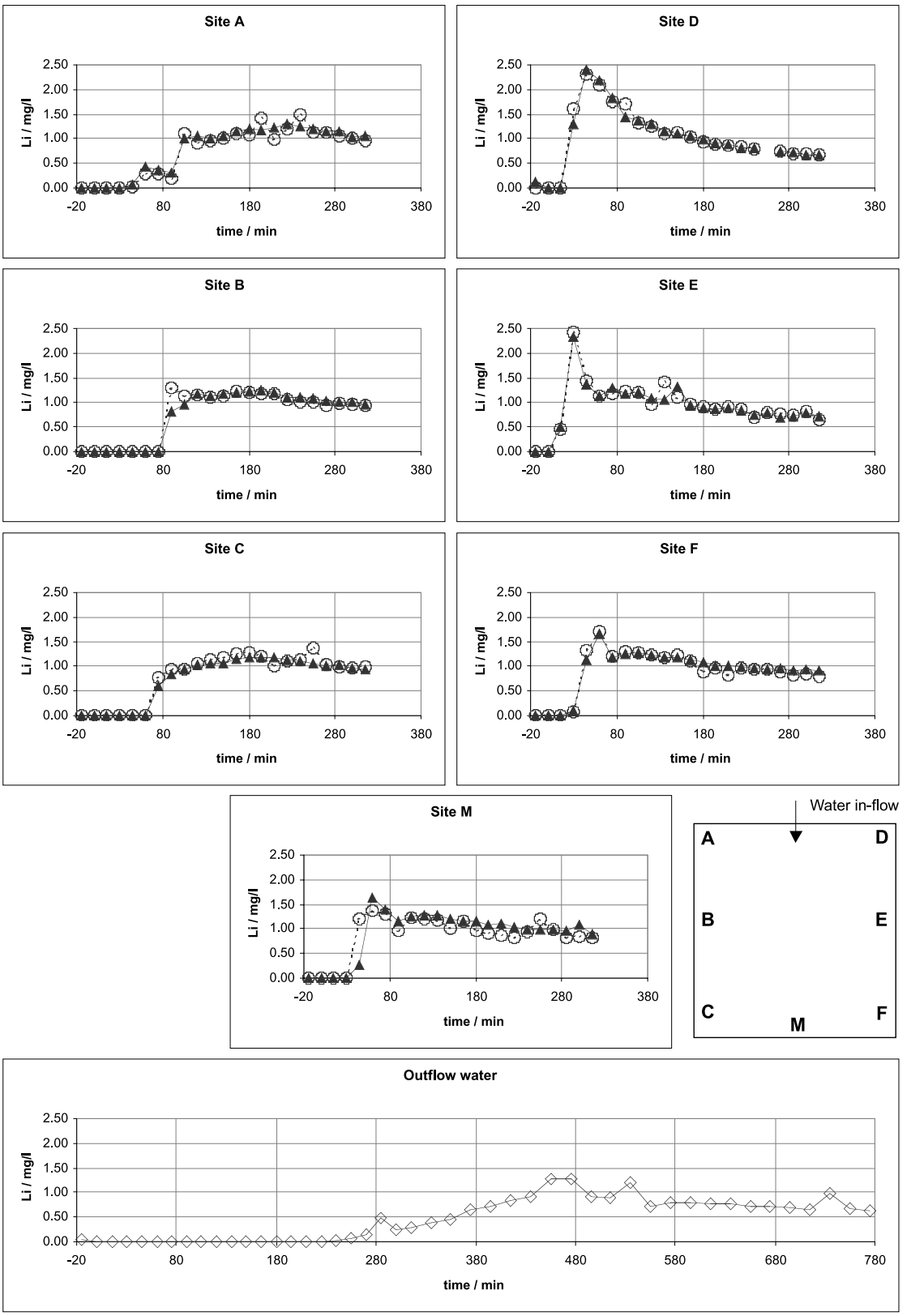

Figure 1 | Lithium concentrations and location of sampling positions in the slow sand filter bed. ▲=surface water, ○=bottom water, ◇=outflow water.

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Table 2 | Components of the schmutzdecke invertebrate community

Predominant groups:
Protozoa
Rotifera
Cladocera (Crustacea)
Copepoda (Crustacea)
Ostracoda (Crustacea)
Chironomidae
Minor groups:
Hydrozoa
Nematoda
Oligochaeta
Asellidae (Crustacea)
Tipulidae (Insecta)
Lymnaeidae (Mollusca)

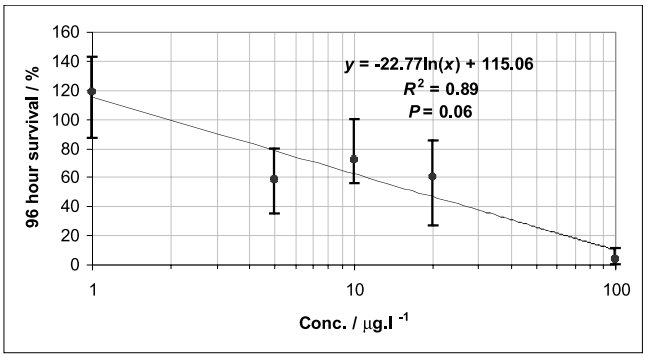

Figure 2 | Dose response curve for chironomid larvae exposed to permethrin. The 96 h survival value represents the mean live:dead larvae ratio in the treatment as a percentage of the live:dead ratio in the control. Error bars represent range of triplicate experiments.

included. The predominant Chironomidae at the time of testing were the Tanytarsini species: *Micropsectra lindrothi* and *Tanytarsus gregarius*.

Subsequent observations were made at both coarse (macro) and fine (micro) scales to record the relative abundance of invertebrate groups. First the schmutzdecke surface and the overlying water in the vessel were examined using a stereoscopic microscope to record the numbers and general activity of the larger organisms. Second, a small aliquot was removed from the vessel and placed on a microscope slide. The field of view was examined to record abundance, diversity and activity of organisms using $\times 40$ magnification. Abundance was recorded on a scale of 1 to 3, where 1 indicates singletons, 3 indicates organisms were too numerous to count and 2 represents an intermediate state. After recording these data the aliquot was returned to the experimental vessel.

Observations were made before dosing and at intervals of 1, 3, 6, 25 and 96 h after the addition of permethrin. At the end of this period the entire contents of the vessels were sorted and the number of live chironomid larvae recorded. It was not possible to establish the numbers of organisms present in the vessels before the experiment started without affecting the structure of the schmutzdecke and damaging the Chironomidae. Hence a trend in the proportion of dead to live chironomid larvae at the end of the period of observation was recorded rather than a reduction in the original population initially present in the sample.

The resulting dose response curve for permethrin is shown in Figure 2, interpolation of which provides a $^{96}LC_{50}$ value of 17 μg/l. This is significantly higher than the corresponding value of 2.9 μg/l reported by Conrad *et al.* (1999) for *Chironomus riparius* derived from a water-only toxicity test (i.e. no sediment present). In our tests, partitioning of permethrin between the water and the schmutzdecke will have reduced the bioavailability of permethrin (Muir *et al.* 1983; Mian & Mulla 1992), and so a higher nominal water concentration is required to achieve an equivalent degree of toxicity compared to water only tests.

The results demonstrated relatively little measurable effect on any components of the schmutzdecke community at concentrations between 1 and 20 μg/l of permethrin. However at the 100 μg/l level there was a total extermination of chironomid larvae and some depression of copepod (microcrustacea) abundance. The abundance

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of protozoans (primarily ciliates) appeared unaffected but there was some indication (i.e. qualitative observations) that their diversity may have been reduced.

Hill (1989) and Conrad *et al*. (1999) report that significant effects on larval density and emergence of adult chironomid midges were observed in experimental ponds treated with nominal water concentrations of 10 μg/l permethrin. At concentrations of 50 and 100 μg/l, Conrad *et al*. (1999) observed the adult emergence was completely eliminated 2 days after application. They concluded that at doses lower than 50 μg/l, older and less susceptible larvae can survive and subsequently emerge. Burton (1991) has reported that first instar larvae are more susceptible to toxicants than older larvae in freshwater sediment environments.

As a result of our observations and those from the literature (Hill 1989; Conrad *et al*. 1999) a nominal water concentration of 100 μg/l was selected for treatment of the filter bed. The highest effective dose was chosen because: (i) a rapid effect was desired to achieve a mortality rate as close as possible to 100%; (ii) older (i.e. 3rd and 4th instar larvae) needed to be effectively eliminated; and (iii) the potential short residence time of permethrin in the filter bed environment, owing to adsorptive/degradative processes and possible transport out of the filter bed.

Filter treatment and monitoring

To achieve a nominal concentration of 100 μg/l in the filter water (1,040 m^3) requires the addition of 104 g of permethrin. PermasectWT is supplied as a 2% w/v solution of permethrin in ethanol, and so a 5 l dose of PermasectWT was applied, yielding a theoretical instantaneous permethrin concentration of 96 μg/l. The actual water concentration will be less than this owing to the relatively high partition coefficient of permethrin (log $K_{oc} = 4.8$) (Mackay *et al*. 1997), and accordingly permethrin has been observed to undergo rapid partitioning to suspended solids and to sediment in aquatic systems (Conrad *et al*. 1999).

The PermasectWT was added as a single dose by pouring it into the inflowing stream of water and was observed to disperse within 1 h. The schmutzdecke and filter water were manually sampled from the edge of the filter bed at 5 points around the filter (sites A, C, M, D and F in Figure 1). Sampling occurred immediately before treatment ($t = 0$), and then at intervals of 1, 3 and 6 h, and 1, 2, 7, 14, 21 and 28 days after treatment. Water from the outflow was collected in pre-cleaned 400 ml glass bottles using an automated EPIC programmable sampler at a rate of 1 sample per hour for a period of 48 h to monitor for possible breakthrough of unretained permethrin ($N = 48$). Samples of outflow water were also manually collected at 7, 14, 21 and 28 days after treatment ($N = 4$).

Schmutzdecke samples ($N = 50$) were collected using a 250 μm mesh pond net. Sub-samples for chemical analysis (permethrin and organic matter content) were placed in pre-cleaned glass jars and stored in refrigerated, insulated boxes for transport to the laboratory. The volume of the remaining sample was recorded and the number of chironomid larvae were counted in replicate samples and their relative activity recorded, which was classified as either: alive; reduced activity (some voluntary movement); moribund (sluggish movement only when stimulated); dead. The data were recorded as numbers/100 ml schmutzdecke. Two observers were used for counting and results were cross-checked for quality control purposes.

Filter water samples ($N = 50$) were collected by submerging pre-cleaned 1 l glass bottles below the surface of the water. These were also stored in refrigerated, insulated boxes for transport to the laboratory where they were analysed for permethrin.

On day 29 after treatment, the filter was drained and core samples of the filter bed were manually collected using a 2.5 cm diameter core tube. Five cores were taken, one each from the corners of the filter and one from the centre. Separate samples of the upper sand layer, the GAC and the lower sand layer were collected from each location and handled as for schmutzdecke samples.

Biological monitoring

The filter bed micro-fauna community in the schmutzdecke was monitored over a 28-day period after treatment on 18 April. Data for the chironomid larvae

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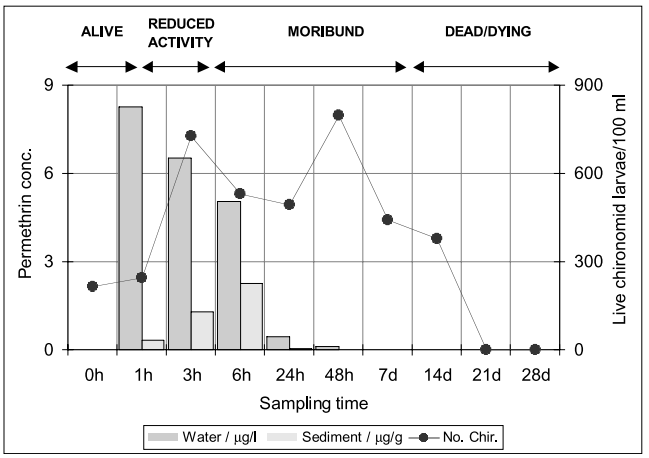

Figure 3 | Numbers and status of live chironomid larvae in the schmutzdecke and corresponding mean concentrations (N=5) of permethrin in the overlying water and the schmutzdecke.

populations are illustrated in Figure 3. One hour before treatment, chironomid larvae were found to be active and numerous (220/100 ml). One hour after treatment, there was observed reduction in activity of individual larvae but an apparent increase in their total number. This was a result of larvae abandoning their tubes (possibly a response to chemical stress from permethrin), thus making them more visible. After 3 h the majority of larvae were in a moribund state. After 7 days all larvae found were dead or dying. At the end of the experimental period no chironomid larvae older than the second instar stage were found in the schmutzdecke samples. The associated micro-organisms (Table 2) were well represented at this time and only a single first instar chironomid larva was found in two of the replicate samples.

These results suggest that the treatment was effective in eliminating chironomid larvae and no adverse affect was noted on the majority of the rest of the micro-organism community. Furthermore, despite a month of opportunity for re-colonisation by egg-laying females from other beds, no massive re-invasion of the filter bed by chironomids had taken place. This was tested on the 16 May by sweep-netting in the open water of the filter bed, from which only 2 larvae were found compared with an adjacent untreated bed where 215 larvae were caught. If re-colonisation had taken place, large numbers of first instar chironomid larvae would have been recorded in these samples as this larval stage is usually distributed throughout the water column.

Chemical monitoring

Permethrin was analysed according to the methods of Long *et al.* (1998). In brief, schmutzdecke and filter bed core samples (1 g dry weight) were extracted with super-critical CO_2, and water samples (1 l) were extracted using solid phase extraction C_{18} cartridges. Analysis was performed by gas chromatography with mass spectrometry (GC-MS). All results are expressed as the sum of the *c*- and *t*-permethrin isomers. The mean analytical recovery of permethrin from fortified samples was $75 \pm 20\%$ for water ($N = 5$) and $81 \pm 15\%$ for sediment ($N = 5$). Sample data have not been adjusted for recovery. The detection limits for permethrin in the water and schmutzdecke samples were 0.01 µg/l and 0.02 µg/g, respectively. All schmutzdecke samples are presented as dry weight concentrations.

Concentrations of permethrin in individual samples ranged from <0.01 to 15 µg/l in filter water and from <0.02 to 4.3 µg/g in the schmutzdecke (Figure 3). Permethrin was undetectable (i.e. <0.01 µg/l) in the water at 7 days after treatment and undetectable in the schmutzdecke (i.e. <0.02 µg/g) at 48 h after treatment. No permethrin was detected in the outflow water at any time or in any of the filter bed core samples.

The mean organic matter (OM) content of the schmutzdecke over the experimental period as measured by loss on ignition at 450°C was 16% by dry weight (range 8–24%). This value is lower than might be expected given the high density of larvae present, however it can be explained by the predominance of diatoms in the schmutzdecke, the frustules of which formed a large portion of the dry mass. The data presented in Figure 4 suggest that the organic matter content of the schmutzdecke may have increased during the initial part of the treatment period, and peaked at the same time as the numbers of observed chironomid larvae. There is a low degree of correlation between OM and number of chironomids ($N = 10$, $R^2 = 0.34$, $P = 0.08$).

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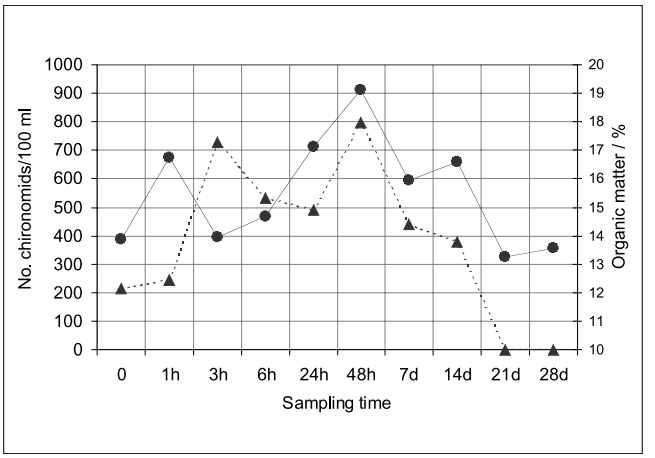

Figure 4 | Organic matter content of the schmutzdecke and number of observed chironomid larvae. ●=mean no. chironomid larvae (N=5), ▲=mean organic matter content (N=5).

Table 3 | Toxicity of permethrin and its major metabolites to *Daphnia magna* (data from Hill 1985)

Compound	$^{48}EC_{50}$ (µg/l)
Permethrin	6×10^{-1}
3-(2,2-dichlorovinyl)-2,2-dimethyl cyclopropanoic acid	1.3×10^{5}
3-phenoxybenzyl alcohol	8.5×10^{4}
3-phenoxybenzoic acid	1×10^{4}

DISCUSSION

It is important to note that the results and subsequent discussion relate specifically to slow sand filters of the GAC Sandwich™ design described previously and different results may pertain in other designs of water filter.

Following treatment, the permethrin concentration in the filter water was observed to achieve a maximum immediately after dosing, after which it rapidly declined as it was adsorbed by the schmutzdecke and/or degraded. The first-order disappearance (i.e. degradation and/or adsorption) half-life ($t_{1/2}$) was 15.3 h. Rapid water to sediment transfer of permethrin in pond mesocosms has previously been observed (Yasuno *et al*. 1988; Conrad *et al*. 1999). In a model aquatic ecosystem, aimed to reproduce conditions in a riverine environment, permethrin introduced at water concentrations of 4 and 20 µg/l was observed to have a $t_{1/2}$ value of between 1.1 and 3.6 days, attributed to biodegradation processes (Lutnicka *et al*. 1999).

Permethrin levels in the schmutzdecke increased rapidly in the first 6 h after dosing, after which they rapidly declined. This can be attributed to degradation owing to the fact that no permethrin was detected in the filtered water. It is possible that a non-extractable bound residue of permethrin developed in the schmutzdecke, but the high analytical recovery reported above suggests that if this did occur, it was not significant. The toxicity to *Daphnia magna* of the major metabolites resulting from permethrin biodegradation are presented in Table 3 from which it can be seen that they are several orders of magnitude less toxic than permethrin. No toxicity data for these chemicals are available for chironomids. Further research on the formation, toxicity and fate and behaviour of permethrin metabolites to invertebrates is required. Measurement of the metabolites would also assist in determining the ultimate fate of permethrin in the filter bed, i.e. to help distinguish between degradation and adsorption.

At the end of the test period there was no evidence of re-colonisation of the filter bed by chironomid larvae. This suggests the possibility that the schmutzdecke was still toxic to chironomid eggs and/or larvae. It has been reported that sediment containing approximately 1 ng/g permethrin (i.e. 0.001 µg/g, twenty times lower than the detection limit used in this study) was lethally toxic to Hexagenia (mayfly) nymphs after a 1 week exposure (Friesen *et al*. 1982). If there is a low level residue (i.e. <0.02 µg/g) of permethrin remaining in the schmutzdecke after a couple of weeks, it is possible that the schmutzdecke may remain toxic to midge eggs and first stage larvae.

Operational procedures involving draining and maintenance of the filter bed prevented us from carrying out

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detailed experiments on the treated schmutzdecke. However, to test the hypothesis of residual toxicity, aliquots of untreated and treated schmutzdecke were collected 3 weeks after dosing and maintained as described for the mesocosm study. Each aliquot was inoculated with chironomid larvae obtained from untreated filter beds. This showed that the larvae were able to survive for at least 48 h on treated schmutzdecke taken from the dosed bed 3 weeks after application of the permethrin. Therefore, there appears to be no acute toxicity to chironomid larvae from contaminated schmutzdecke but we were unable to test for chronic toxicity which may account for the lack of evidence of colonisation in the filter bed. Further research on the chronic toxicity of low levels of sediment phase permethrin to chironomid larvae is required to explain this.

Contrary to our findings, rapid recovery and subsequent emergence of chironomid midges from experimental ponds treated with permethrin has been observed. Conrad *et al*. (1999) recorded adult emergence within 4 weeks of treatment of a pond treated with a nominal permethrin concentration of 100 μg/l. Furthermore, levels of emergence were comparable with or greater than levels of emergence from a control (i.e. untreated) pond within 2 months. Rapid recovery by other invertebrate species in aquatic systems treated with or exposed to permethrin has also been observed (Mian & Mull 1992). In light of these findings, it is difficult to explain why a rapid recovery was not observed in the filter bed. In contrast to experimental ponds, the filter bed is a dynamic system continually being flushed with oxygenated water and it can reasonably be expected that permethrin will have a shorter residence time in this type of environment. It is possible that the schmutzdecke was adsorbing and retaining permethrin without it being biochemically degraded, and thus acting as a long-term reservoir for permethrin uptake by chironomids via ingestion. Differences in observed toxic effects of permethrin in the two types of system may thus be related to the bioavailability of permethrin under different conditions.

One further concern of chironomids in slow sand filter beds is the fact that it has been shown that midge larvae play an important role in the functioning of slow sand filters (Wotton *et al*. 1996; Wotton & Hirabayashi 1999). If chironomid larvae are controlled using this method on a regular basis, it may have implications for efficiency of the biofiltration component of the filter bed over time periods longer than the study time used in this experiment. No adverse affects on filter bed operation were recorded during this experiment. If this method were to be adopted for full-scale implementation, filter bed performance should be closely monitored.

CONCLUSION

These results suggest that the application of permethrin to control chironomid midge emergence from slow sand filters has been effective over the timescale studied and did not result in the appearance of permethrin in the treated water at a concentration above 0.01 μg/l. A single treatment at a nominal water concentration of 96 μg/l permethrin (100 g total) was effective in exterminating chironomid midge larvae in the slow sand filter bed and eliminating adult midge emergence for a period of at least 28 days.

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