Management of the Environmental Inputs and Risks of Cypermethrin-based Sheep Dips

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FINAL REPORT V1
VM02504

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MARCH 2009

CSL Project No.:	R3SV
Client Project No.:	VM02504
Report Status:	Final v1
Dissemination:	Public
Report prepared by:	C Ramwell
Report approved by:	
Date:	

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EXECUTIVE SUMMARY

The marketing authorisation for cypermethrin-based sheep dip products has been suspended following a number of reports of serious water pollution incidents. Previous pilot studies have demonstrated that, even when following good agricultural practice, cypermethrin has the potential to reach surface waters.

The overall aim of this study was to investigate further the environmental risks arising from the use of cypermethrin-based sheep dips. Experimental and desk-based studies were performed to:

1) Investigate losses from fleece with prolonged drying times between dipping and entering a stream,
2) Explore approaches for reducing inputs of cypermethrin to the aquatic environment,
3) Assess relative risks of different exposure routes,
4) Develop an understanding of post-dip sheep handling practices, and
5) Propose possible risk management options for controlling the releases of cypermethrin from sheep dip to surface waters.

Objectives 1 and 2 were performed on a working sheep farm – the same farm that was used in a previous study, to enable comparison between the results. The farmer prepared the dip bath using Cyperguard (the equivalent of Auriplak and Ecofleece) and dipped his sheep as normal. The sheep were left to drip for 10 minutes before being released to the next holding area. It was postulated that, as excess dip will gravitate down the sheep, it may be possible to reduce the total quantity of dip retained by the sheep without affecting its efficacy by washing off any excess in a footbath – this would also be relatively easy and cheap for the farmer. To this end, after dripping, some sheep were sent through a footbath containing water, some through a footbath containing water + animal shampoo, and others were not sent through a footbath (the control). Sheep from these three treatments were colour-marked and turned out to pasture. Sheep from each treatment were brought back to the farmyard after set time periods (drying times) of 1, 2, 3, 7, 14, 21, and 28 days. The sheep were herded through a trough of water (~ 0.1 m deep) simulating a small stream. Samples of the water were taken and subsequently analysed for cypermethrin. Once a sheep had been through the trough it was excluded from further participation in the study. A further set of sheep was kept indoors with straw underfoot for 24 hours after dipping before entering the trough of water.

Overall mean losses of cypermethrin (including all treatments) were 508, 590, 494, 234, 107, 54 and 55 ug per sheep for drying times of 1, 2, 3, 7, 14, 21, and 28 days respectively. Losses at 1, 2, and 3 days were signifcantly ($p < 0.01$) greater than losses after a drying time of 7 days or more; losses after 7 days were significantly ($p < 0.01$) greater than losses after a drying time of 14 days or more, and

losses after 14 days were significantly ($p < 0.01$) greater than losses after 21 or 28 days. There was no significant effect of the water, or water + shampoo footbaths on the total quantity of cypermethrin subsequently removed by water in the trough. There was no significant difference in quantities of cypermethrin removed when the sheep had been kept indoors compared to those kept in pasture. These results demonstrated that even after four weeks (and > 180 mm of rainfall) > 50 µg of cypermethrin could be washed off each sheep.

This mass of cypermethrin removed from the farmyard (study VM02502) was divided by the mass removed from the fleece after different drying times (current study) to give the number of sheep that would be required to enter a stream to give an equivalent farmyard loss, thus providing insight into the relative importance of the farmyard and the sheep entering a stream as exposure routes. In 4 out of 5 rain events, cypermethrin removed from the equivalent of < 2 sheep (drying time up to 3 days) and < 15 sheep (drying time up to 4 weeks) equalled losses from the farmyard demonstrating the importance of the sheep as a source of cypermethrin. However, in the remaining rain event (study VM02502), which lasted over 8 hours, a substantial quantity of cypermethrin was removed from the farmyard (~16 mg) illustrating that the farmyard should not be discounted as a significant exposure route. It was also noted that losses from the farmyard are in response to rainfall, thus receiving waters are likely to contain much more dilution water than when a sheep voluntarily enters a stream, i.e. at times of low water levels.

The TOXSWA model (originally developed to calculate exposure concentrations in surface water for the ecotoxicological risk assessment of pesticides) was adapted to an upland sheep farm scenario. A number of scenarios were modelled where the stream was small, medium, or large with either 1 or 10 different sheep entering on a daily basis, or 1, 10, or 300 sheep entering after 1, 14, or 28 days after treatment.

As could be expected, PEC values in water were directly proportional to the number of sheep entering the stream and the concentrations were highly dependent on the size of the stream so the PEC values in water were at least 10 times smaller in the large stream than in the small stream. The pattern of PECs was the same for all scenarios where the sheep entered on a single occasion, i.e. an initial peak followed by a rapid decline. At the maximum (water) concentration, 23% of the cypermethrin in water was associated with suspended particles in the stream. This percentage increased when the concentration in water declined. Although just one sheep could cause a PEC > 2 ng/L in a small stream, the concentration had declined to < 0.4 ng/L within an hour and there was a very rapid decline in PECs in the first two hours since the sheep entered the stream. Even when 300 sheep entered the stream just one day after dipping the PEC was < 2 ng/L within 4 hours, but it took over 24 hours for the PEC to decline to < 0.1 ng/L. The concentration in sediment declined slowly, partly due to degradation of the cypermethrin, but mainly due to diffusion back into the water. This diffusion back into the water phase was not matched by any concurrent increase in cypermethrin in the water phase due to the rapid throughflow of water distributing the compound downstream. Consequently, after the initial input, water concentrations continued to decline despite inputs via diffusion.

Where sheep entered on a daily basis the concentration in water was strongly influenced by the day since treatment, and both the maximum concentration and greatest time weighted average concentration (TWAC) in the water phase occurred on the first day after treatment. However, in the bottom sediment, accumulation of cypermethrin was apparent and sediment concentrations reach a maximum on the fourth day, with the greatest TWAC occurring on day seven.

Data from study VM02502 (i.e. farmyard losses) were also input into the model. Cypermethrin concentrations were short-lived in the water phase as illustrated by the rapid decline in the PEC, and the much lower 24 h-TWAC compared to the peak concentrations; 24h-TWACs were ten times lower than the maximum PECs. This compares to concentrations in the sediment that were not even halved when comparing the 24h-TWAC to the maximum PEC. This effect is due to the rapid throughflow of clean water and the downstream migration of cypermethrin.

Environment Agency monitoring data on cypermethrin concentrations in water and sediment were compared to the modelling results. It was feasible that the concentrations detected by the EA could arise without the misuse of the compound.

Visits to farms indicated that sheep had access to surface water when in pasture on over 90% of farms; 30% needed to cross streams to return their sheep to pasture. Farmers were aware of the need to keep sheep away from water for at least 24 hours, but any longer was largely considered impractical. Dripping times in showers were less than for static baths. Half the farmers dipped twice a year (summer and autumn) and half dipped only once a year. Over 90% of the farmers used organophosphates (OPs) and only two farmers exclusively used synthetic pyrethroid (SP) as their dip of preference. All farmers disposing of dip to land had a groundwater authorisation licence. All the static drip pens drained back into the bath. Drip times typically ranged from 10 to 30 minutes for static baths; for showers it was < 5mins. Opinion was divided as to whether it was practical to increase drip times; faecal contamination was the primary reason for not increasing dripping times, but the lack of evidence as to why it was necessary was also a factor.

Proposals by the EA to reduce pollution by sheep dips received mixed reaction. There was agreement that new facilities should be built to the specification of some of the proposals, but it would be far too costly to alter existing facilities. It was noted that any requirement to have 2 drip pens could back-fire in terms of environmental contamination as farmers with a single drip pen would probably just halve the existing pen, thus there would be less room for the sheep to shake, so they would retain more dip which could subsequently be taken into pasture. On the whole, fencing watercourses was seen as totally impractical, and it would be prohibited on some common land (e.g. National Park, MoD) and other problems could arise associated with providing alternative water supplies. It was considered more feasible to build bridges, but these would be very costly and require more infrastructure and resources than a bridge alone; options would have to be considered on a case-to-case basis.

Other mitigation options could include co-ordinated dipping with neighbouring farms, catchment sensitive farming, cypermethrin-approved farms and/or assessing farm-layout to identify risk on an individual farm basis.

Farmers raised the issue of withdrawal periods for other treatment methods (e.g. injectables) and highlighted that it was not that simple to replace one treatment method for another.

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1 INTRODUCTION

Sheep can suffer from a number of skin parasites that cause ill health and suffering, thus it is essential to prevent and control such infections. Dipping is the most effective method of treating a wide range of parasites[1], but there have been several pollution incidents over the past few years involving sheep dips. Between 2002 and 2004 there were a total of 18 aquatic incidents reported to VMD that may be attributed to sheep dips, but these numbers rose to 77 incidents in 2005, reflecting the increase in monitoring activity by the Environment Agency (VPC Annual Report 2006). Consequently, the market authorisation for cypermethrin-based sheep dips was suspended in February 2006.

Environment Agency (EA) investigations indicate a number of potential routes of exposure, including: 1) cypermethrin contained in runoff from hard surfaces within the farmyard, and 2) removal from the fleece when sheep enter streams. The current guidelines (Groundwater Protection Code: Use and Disposal of Sheep Dip Compounds[2]) advise that sheep should be kept away from water courses for at least 2 weeks after dipping “where at all possible”, thus acknowledging that this is not always practical. However, even after 2 weeks sheep dip product may remain on the fleece and literature supplied with the dip products states that the dip can remain on the sheep for several months.

Two recent exploratory studies funded by VMD (VM02502: Cypermethrin losses from a farmyard, Sinclair et al., 2007) and the EA (Cypermethrin loss from sheep fording a stream, Ramwell et al., 2007) have demonstrated that these two exposure routes do indeed have the potential to pollute surface waters, even when Good Agricultural Practice is applied. However the data are currently not sufficiently robust to enable risk management decisions to be made. For example, the findings of the EA study demonstrated that significant losses could occur when a sheep forded a simulated stream, but the period of investigation did not exceed two days after dipping. There remains a need to further explore these routes of exposure and to explore potential risk management options.

The overall aim of this study was to further investigate the environmental risks arising from the use of cypermethrin-based sheep dips. Experimental and desk-based studies were performed to:
1) Develop an understanding of post-dip sheep handling practices,
2) Investigate losses from fleece with prolonged drying times between dipping and entering a stream,
3) Explore approaches for reducing inputs of cypermethrin to the aquatic environment,
4) Assess relative risks of different exposure routes, and

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[1] www.defra.gov.uk/animalh/welfare/farmed/advice/posters.pdf

[2] http://www.defra.gov.uk/environment/water/ground/sheepdip/pdf/code.pdf

5) Propose possible risk management options for controlling the releases of cypermethrin from sheep dip to surface waters.

The study was divided into three main phases consisting of a field study, farm visits, and desk-based modelling work. It was originally intended to perform one detailed study and at least one other smaller study on another farm using a different sheep breed to accommodate animal size and/or fleece length. However, in practice it became apparent that the single detailed study would be more intensive than anticipated due to the logistics of incorporating several drying times and management options into one study whilst simultaneously minimising the number of sheep used as it was also tupping season. It was therefore considered more appropriate to focus resources on conducting a single study in detail, rather than a two- or three-farm study in less detail.

2 FIELD STUDY

The previous EA study investigating the removal of cypermethrin from fleece when sheep ford a simulated stream demonstrated that losses were in the order of milligrams per sheep and that these losses decreased with increasing drying times, where the longest drying time was 48 hours. Current guidelines relating to sheep dipping practices advise farmers to keep sheep out of surface water for at least two weeks after dipping, where possible, although there is no scientific basis for this time period. Data are therefore required to provide evidence to support the current guidelines.

The findings of Ramwell et al., 2007 demonstrated that there was a significant decline in cypermethrin losses in the hours immediately after dipping with losses up to 1 hour after dipping (~ 1 mg/sheep) being twice that compared to losses after 2 and 4 hours. It was therefore postulated that one mitigation technique to reduce cypermethrin contamination would be to remove any excess dip solution in a controlled manner shortly after dipping, thus reducing the quantity subsequently available for removal should a sheep enter a stream. Field studies were designed to test this theory and the aims of the field work were to investigate:

1. the influence of drying time on the removal of cypermethrin from sheep fording a stream, and
2. whether mitigation techniques could be employed to reduce the transfer of cypermethrin beyond the holding pen.

The drying times investigated were: 1, 2, 3, 7, 14, 21 & 28 days between dipping and fording a stream, thus providing evidence to determine whether current guidance of keeping sheep away from water for at least 2 weeks was indeed best practice.

It is imperative that any mitigation option is easy to implement, and preferably low cost, if it is to be adopted on a scale that is beneficial to the environment. The mitigation options proposed were to run the sheep through a footbath of either water, or animal shampoo, on release from the holding pen. This action could remove any excess dip that has drained downwards on the animal, thus reducing the quantity of cypermethrin that could potentially be transferred to surface waters by the sheep. Placing the footbath between the holding pen and pasture, rather than the drip pen and holding pen had the advantage that more excess dip could drain off the sheep and thus be removed in the footbath and it would be infinitely easier for the farmer to operate.

In addition, the effect of keeping sheep indoors vs outdoors was investigated for the one and two day drying time. This had the effect of investigating straw as a sorbent compared to grass and being exposed to the elements, although such a mitigation option may have limitations in practice due to costs. In all cases, three sheep per replicate were used and there were three replicates per test.

2.1 Study protocol

The study was undertaken on a farm near Grassington, North Yorkshire. The farm had previously been used in the EA study. The advantage of using the same farm was that the results would provide an indication of the replicability of the scientific approach, and the effect of fleece length could be considered - in 2006 the sheep were dipped in the summer and had a fleece growth of a few weeks, as is standard practice, whereas in the current study (autumn 2007), the sheep had a fuller fleece growth.

The test material was a microemulsion concentrate containing cypermethrin (high cis 80/20) 10% w/w for the control of blowfly strike, lice, keds and ticks (Cyperguard (Batch PME 022A) supplied by Cross Vetpharm; Cyperguard is equivalent to Ecofleece and Auriplak). The study was performed under Animal Test Certificate 16714/0001. The dip solution was prepared by the farmer following label advice. Two litres of dip concentrate were diluted into 1000 L of water in a 350 gallon (1591 L) plastic, circular bath. No further dip was added to the bath, as the dip volume did not decrease significantly. The sheep were a mixture of pure Swaledales and Swaledale-Blueface Leicester mules and they had approximately 3 months fleece growth since shearing. The sheep were dipped on 7 November 2007 by the farmer and his assistant following normal practice. After leaving the bath, the sheep remained in the initial drip pen (drain pen - where any dip draining from the sheep flows back into the bath) for 10 minutes in line with current guidelines.

On leaving the drip pen, 81 sheep were moved to a holding pen with no further action (i.e. ‘controls’). A further 81 sheep were sent through a footbath (3 m long) containing 90 L of water; these sheep were marked with a green spot on their rump. The water from the footbath was pumped out into a waste container and the footbath rinsed with fresh water, which was also pumped out to waste. The footbath was then filled with animal shampoo (Evans Vanodine International Animal Shampoo; Batch LA0161) and this was prepared as per the label (2.5 L shampoo in 90 L water). The product was chosen on the basis that it is a readily-available commercial animal shampoo that was stocked in a local agricultural suppliers. A further 63 sheep were sent through the footbath containing shampoo and marked with an orange spot on their rump. The test groups are referred to as control, water and shampoo henceforth. Whilst it would have been preferable to randomise the order in which the animals used for the different treatments went through the dip, this was not logistically possible and the ‘benefits’ of this could not be justified in terms of the stress it may cause the sheep with the increased handling that would be necessary to accommodate this experimental design. It was known from the previous EA study (Ramwell et al., 2007) that there was no significant difference in losses for drying times of 1 and 2 days, thus the extra hour or so of drying time for the first sheep dipped would not undermine the validity of the study. The ‘control’ animals were dipped first as these had no further immediate involvement (‘treatment’ or marking) thus they could be turned out to adjacent pasture. The water treatment was applied to the next animals dipped to ensure that the footbath did not contain any residues of shampoo; even though the footbath was rinsed between treatments, this treatment order avoided any possibility of cross contamination.

Another potential factor that may have been introduced by not randomising the animals/treatment was that the concentration of the starting dip could potentially decrease with the increasing number of animals through the bath and the concentration of the dip for the ‘shampoo’ animals potentially could be lower than for the ‘controls’. However, it is unlikely that this would be significant for the duration of the study as 1) the product is designed to be used for a number of sheep and the concentration should not decrease significantly when used as instructed, and 2) it is more probable that the length of time for which the animal is in the dip bath is far more influential in determining the quantity of dip that is on each animal. As this is only controlled by the experience of the farmer, there is no reason to assume that the quantity of dip on the first control animals dipped would be significantly greater than the ‘shampoo’ animals. Indeed, three sheep per replicate were used as an attempt to account for some of the natural variation that could occur in the quantity of dip that may be retained by an animal, whilst ensuring that a minimal number of animals was used.

Eighteen control sheep and eighteen water sheep were held in separate pens in a barn with a straw floor. These were the ‘indoor’ sheep, but their purpose was twofold as these sheep would provide data to enable better comparison between the current study and that of 2006. In the EA study of 2006[3], drying times were in the order of hours with the longest drying times being 1 and 2 days. The sheep were kept in a barn on straw during this holding period. In reality, when a large number of sheep are dipped, the ‘drying time’ will occur when the sheep are held outside in pasture – as in the majority of the current study. Comparison of the results of the current study with those of 2006 could be affected by the introduction of an additional variable of ‘holding location – indoors or outdoors’. The sheep kept indoors thus removed this variable. In addition, it would enable fleece length to be considered as an influential parameter. It is acknowledged that temperature is a variable that will differ between the current project and that of 2006, but this is not practical to investigate as sheep dipped in summer normally have a short fleece, whilst those dipped in autumn have a longer fleece, thus to investigate a long fleece in summer temperatures is nonsensical. A summary of the different treatments is given in Table 1

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[3] Dipping took place in 2006, but the report was not finalised until 2007. Where reference is made to the study of 2006 it is that reported in Ramwell et al 2007.

Table 1 Summary of treatments

	Indoor	Outdoor
Control	1, 2	1, 2, 3, 7, 14, 21, 28
Water	1, 2	1, 2, 3, 7, 14, 21, 28
Shampoo		1, 2, 3, 7, 14, 21, 28

Numbers equate to days after treatment

The sheep were kept in pasture (with the exception of the ‘indoor’ sheep) throughout the study duration and they were therefore exposed to the natural elements. After the specified drying time (1 – 28 days), 27 sheep (9 of each colour marking/treatment – control, water, shampoo) were returned to the farmyard. These were then separated in batches of three to run through the simulated stream, i.e. 3 sheep per replicate, and 3 replicates per treatment. The sheep were marked with a blue spot after they had been through the trough to indicate they had been used. They were then returned to pasture and took no further part in the study.

The simulated stream consisted of a metal trough, 1.8 m long x 0.6 m wide x 0.3 m deep, containing 100 L of water giving a water depth of 9.3 cm. Although 9.3 cm was an arbitrary depth it was a reasonable value and it approximated to the water depth (3”) that the farmer considered, through experience, that the sheep were comfortable with; a greater depth could be dangerous for a sheep to cross under real conditions, and where a stream is deeper it tends to be narrower and sheep would jump across rather than go through a stream out of preference. Four 25-L carboys were used to transfer water to the trough; although the water emanated from a tap, the actual source was a surface stream and there was no filtration, or other treatment. (It was noted after particularly heavy rain that the water from the tap was discoloured. On one occasion it was necessary to use some discoloured water, and only 25 L was used per trough to spread the effect.) The trough water was stirred prior to taking two 500-ml samples using a glass jug after three sheep (i.e. one replicate) had run through the trough. The water was then pumped to a waste container and both the glass jug and the trough were dried and cleaned with methanol before repeating the procedure for all replicates and tests. Although the integrity of the cleaning method was not quantified in the current study, it can be expected that cypermethrin residues were negligible based on the fact that the cleaning method used was identical to that used in VM02502, and the quantities of cypermethrin entering the troughs during tests in the current study were much lower than that in VM 02502 where it was demonstrated that the maximum residues remaining after cleaning were 23 ng/L (33% of replicates; for 66% of replicates residues were < 10 ng/L (LOD)). Tap water from the farm (500 ml) taken from the carboys served as field blanks, and additional tap water was spiked with a known amount of stock solution (analytical grade cypermethrin in ethyl acetate) on each day a test was undertaken in order to monitor integrity of the samples during storage. All samples were given a unique identifier and stored in glass bottles at 5°C prior to analysis.

Rainfall data were supplied by the Environment Agency via their monitoring network. Daily rainfall amounts were recorded at a station ~ 3 miles down the same valley.

2.2 Data analysis

The measured concentration was multiplied by the volume of water in the trough (100 L) to provide a mass of cypermethrin. This was divided by the number of sheep through the trough to give a mass per sheep. There were two exceptions to the rule of three sheep being used per replicate. On one occasion only two sheep were available for the replicate, and on another occasion, one sheep managed to walk through the trough three times. This was accounted for when calculating losses per sheep and the relevance of the findings is discussed in the results section. Analysis of variance was conducted on the mass of cypermethrin lost per sheep (to account for the discrepancies discussed above) using Excel.

2.3 Chemical analysis

The analytical method used was the same as that used in the previous VMD cypermethrin monitoring study (Sinclair et al., 2007). Samples were allowed to warm up to room temperature. The sample was then thoroughly mixed by quickly inverting the bottle several times. The samples were clean (in terms of environmental water samples) with only a small amount of very fine sediment visible, thus there was no requirement to filter, or centrifuge the sample – steps that inherently increase the risk of introducing error into the analysis - and, as such, total cypermethrin was quantified. Sample (300 ml) was measured out gravimetrically into a 400 ml glass beaker and transferred to a 500 ml glass separating funnel. The beaker was rinsed with dichloromethane (DCM) (50 ml) and the rinsings added to the separating funnel. Each sample was then fortified with permethrin as an internal standard. The separating funnel was shaken vigorously for at least 1 minute, then left to stand for at least 10 minutes for the aqueous / DCM layers to separate. Sodium chloride (~10 mg) was added to reduce emulsion at the aqueous / DCM boundary. The DCM layer was filtered through a glass funnel containing anhydrous sodium sulphate (pre-washed with 30 ml of DCM) into a 250 ml round bottomed flask.

Extracts were concentrated by rotary evaporation at 35ºC to approximately 10 ml, then transferred to 15 ml glass concentrator tubes by glass Pasteur pipette, using small portions of DCM to rinse out the flasks. The extracts were concentrated to dryness using a stream of dry nitrogen at 40ºC and reconstituted into ethyl acetate (100 - 200 μL), using a vortex mixer to help re-dissolve any residue. Calibration standards were produced in the range 0.025 - 100 μg ml^{-1} cypermethrin in ethyl acetate, also containing 0.2 μg ml^{-1} permethrin. All standard solutions were stored in amber glass vials at +2-

7ºC, and stock solutions at ≤ -20ºC. Four replicate matrix-matched (i.e. tap water from the farm) control samples (300 ml) were spiked with a known concentration of analytical-grade cypermethrin (and permethrin) diluted in ethyl acetate to quantify method recovery; farm tap water spiked with permethrin served as blanks for quality control purposes.

The GC-MSD instrumental conditions used for cypermethrin analysis were:

Autosampler:	HP7673
GC:	HP5890 series II
Detector:	HP 5971 MSD
Injector:	On column
Column:	Agilent HP-5MS 30 m (nominal) x 0.25 mm i.d., 0.25 µm film thickness (with ~1m 0.53 mm deactivated silica pre-column)
Injector temperature:	Oven tracking
Detector temperature:	320ºC
Oven program:	Initial temperature 100ºC held for 1 minute, then 20ºC / min until 300ºC, held for 5 minutes
Carrier gas:	Electronic pressure control to provide a constant flow of helium at *ca.* (7.1 psi at 100ºC)
Injection volume:	3 µL
Ion detected:	m/z 163.05 used for quantification

All concentrations greater than the lowest calibration level (LCL) that could be reliably determined are reported and these were the sum of four GC peaks, Depending on the final volume used, the LCL detectable was equivalent to cypermethrin sample concentrations of 17-169 ng/L. Recoveries were very good and consistent (110, 113, 115, 130%), reflecting the cleanliness of an uncomplicated matrix. The recovery for the method (117%; replicate average) was not significantly different to unity, thus the results were not corrected for recovery (IUPAC, 1995). The raw data are provided in the appendix.

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A recovery test for the troughs was conducted by preparing a stock solution of the product (1000 mg in 100 ml distilled water), adding a known amount of product using a pipette to a trough containing 100L of water, stirring the solution and sampling as per the normal field trial. Three replicates at two doses (4 ml = 4 mg; 0.2 ml = 0.2 mg) were used. Recoveries were 97% and 66% respectively for the two concentrations – the raw data are presented in the appendix.

3 FIELD STUDY RESULTS

The mass of cypermethrin removed, per sheep, for the different drying times for sheep kept in pasture (i.e. under normal conditions) is illustrated in Figure 1 (showing the mean and ± 1 standard error (se)) with the average overall loss irrespective of treatment summarised in Table 2.

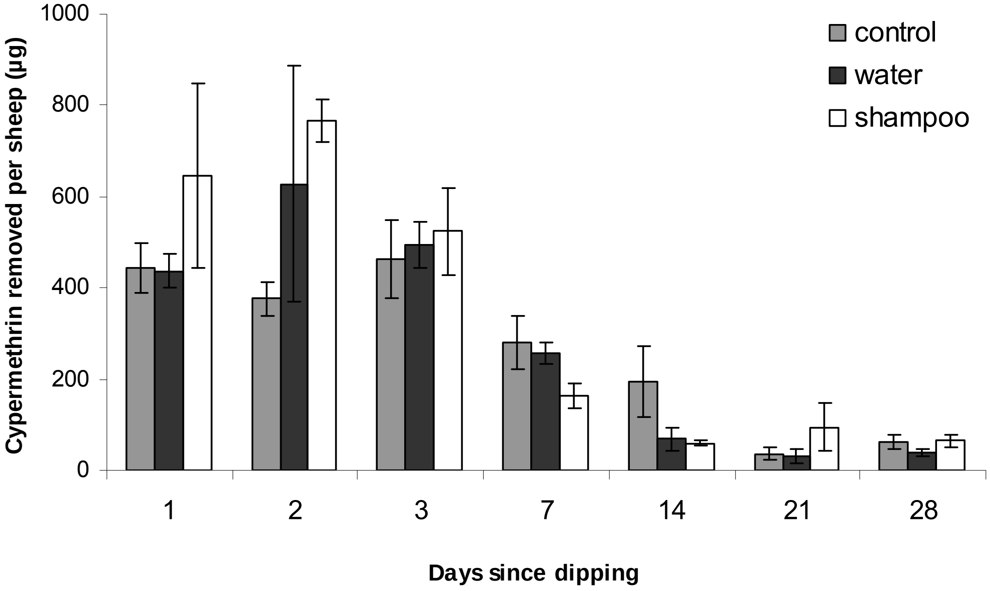

Figure 1 Mass of cypermethrin removed within 4 weeks with different mitigation options showing the mean ± 1 se

Losses after 7 days (234 µg/sheep) were significantly ($p < 0.01$) less than losses after days 1-3 (~ 500 µg/sheep) and losses after 14 days (~ 100 µg/sheep) were significantly ($p < 0.01$) less than losses after 7 days. There was no significant difference between losses after 21 and 28 days (~ 55 µg/sheep), but these were significantly ($p < 0.01$) less than losses after 14 days. (Above is based on single ANOVA after two-way ANOVA revealed no significant impact of shampoo/water).

Table 2 Average loss of cypermethrin irrespective of treatment for sheep kept in pasture

Days since dipping	Overall average loss (µg per sheep)
1	508
2	590
3	494
7	234
14	107
21	54
28	55

It can be seen from Figure 1 that the mitigation option of running the sheep through a footbath containing either water or shampoo when leaving the holding pen did not significantly reduce the quantity of cypermethrin removed when subsequently entering the stream. The data indicate a tendency for cypermethrin losses to be greater for the shampoo treatment at one and two days after treatment (DAT) and it is possible that the shampoo solubilises the cypermethrin, or reduces its sorption to the fleece, making it more available for removal; the apparent reduced effect by Day 3 may be due to the shampoo being washed out. However, there are not sufficient data to corroborate this theory, particularly as it is evident that losses from the water treatment were also greater than the control on Day 2; there was substantial variation between the replicates on this day. The data indicate that a shampoo footbath would not be an effective mitigation option.

Overall, there was no significant difference in losses from the fleece for those sheep kept indoors and those kept in pasture (Figure 2). Figure 2 also illustrates that losses in the current study were within a similar order of magnitude to the 2006 study, where all sheep were kept indoors. Although mean losses appeared slightly lower in 2006 than in the current study the differences were not significant. It is possible that the shorter fleece length in 2006 may have contributed to the slightly lower mean losses. However, the results demonstrate that such differences may be small compared to natural variation in the quantities of dip retained and removed between individual sheep as indicated by the variation between replicates.

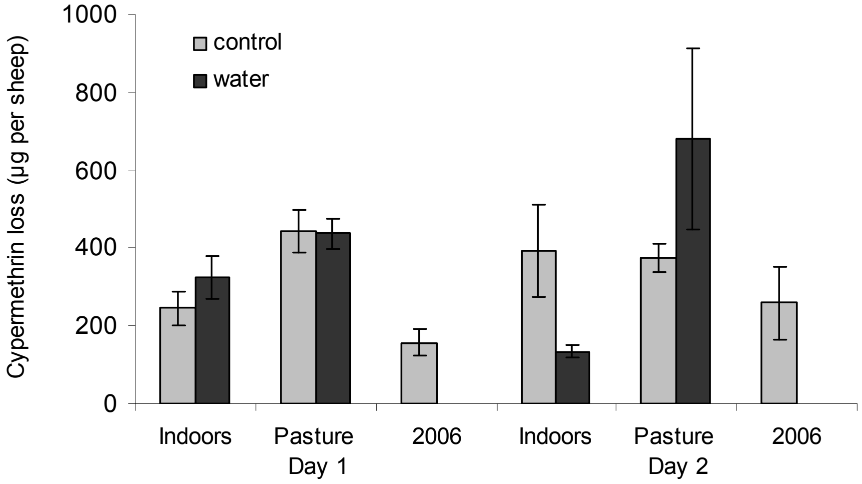

Figure 2 Mass of cypermethrin removed from sheep kept indoors and in pasture compared to 2006 results (indoors) showing the mean ± 1 se.

Although there is no obvious explanation as to why the variation between the replicates was much greater on days 1 and 2 after treatment it is possible that, when the amount of cypermethrin available for removal is very high, the quantity removed is more sensitive to the duration and quantity of sheep exposed to the water. For example, for the control treatment, indoors on Day 1, the measured concentrations for the three replicates were 5.8, 59 and 9.0 µg L^{-1}, giving masses of 93, 1967 and 300 µg respectively. The very high concentration for the second replicate may be attributed to a sheep slipping and falling on its belly in the trough. This replicate has been excluded from the data analysis, and the figures and tables presented in the body of this report, but it is included in the appendix.

Nearly 100 mm of rain fell within the first 3 weeks of the study, and a further 80 mm falling in week four (Figure 3). Despite this substantial amount of rain, particularly between weeks 3 and 4, there was no significant decline in losses from the fleece when fording a stream during the same time period (Figure 1).

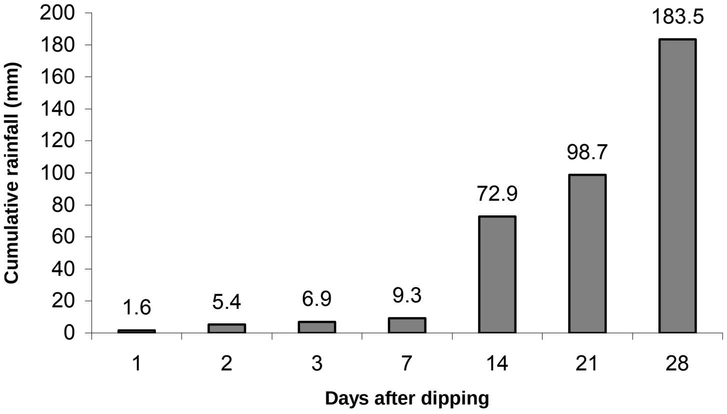

Figure 3 Cumulative rainfall during the study period

Although one sheep managed to walk through the trough 3 times (replicate 2, shampoo, day 28) the concentration was 2.52 µg L^{-1} compared to 2.09 and 1.21 µg L^{-1} for the other replicates, indicating that there was no large effect of the increased exposure time. For the test where only two sheep were available to go through the trough, the concentrations for the replicates were 9.32 µg L^{-1} (2 sheep) and 12.90 and 34.27 for the other replicates with the correct number of sheep (3).

4 PREDICTED ENVIRONMENTAL CONCENTRATIONS

4.1 Background

Excluding the spreading of spent dip to land, the main routes via which cypermethrin may enter surface waters are 1) from the farmyard area during and immediately after the dipping process, and 2) removal from the fleece when sheep enter streams in pasture and/or on their return to pasture. These two exposure routes (termed farmyard and in-pasture respectively) have very different characteristics, and are temporally distinct. Losses from the farmyard require sufficient rainfall to mobilise the cypermethrin and transport it to surface water. When there are losses from the farmyard, stream levels will typically be rising and could continue to do so after farmyard runoff has ceased, and dilution could be significant. This contrasts to in-pasture losses that are more likely to occur when water flows are low. The main reasons for sheep entering surface water are to drink when hot or lactating, or to get to the other side where the stream divides pasture, but, on the whole, sheep will avoid entering water where possible. Sheep do not have a great requirement for consuming water unless lactating, or during warm weather. Pregnant sheep are not dipped, thus the most realistic scenario of contaminated sheep entering water is the need to drink in warm weather. This coincides with low flow conditions. Sheep will not cross fast-flowing water, so if they do enter a stream to get to other pasture, it is more likely that flow will be lower rather than higher. Upland streams have a flashy response to rainfall (i.e. low base flow, but high flood discharge returning to base flow relatively soon after rainfall has ceased), thus sheep will tend to wait until levels drop before attempting to enter the water given their general dislike of water. Consequently, stream discharge is likely to be low when there is the highest probability of a sheep entering the stream of its own accord.

A further difference between the two exposure routes is that for in-pasture losses, there is no opportunity for dissipation of the cypermethrin from source to watercourse, as the source (i.e. the sheep) is in direct contact with the water. This contrasts to losses from the farmyard where dissipation may occur between the farmyard-source and the watercourse. The extent of dissipation will depend on the distance and the nature of the surface over which runoff may occur – dissipation will be greater if the land comprises soil/vegetation rather than a hard surface (e.g. road). Calculations of the predicted environmental concentration (PEC) for the farmyard and in-pasture exposures are considered separately. In the first instance, simple dilution calculations were undertaken followed by more complex modelling. In addition, the relative importance of the different exposure routes was considered.

4.2 Estimated cypermethrin concentrations due to dilution

Data from the VMD-funded study (Cypermethrin losses from sheep farms, VM02502) provided the basis of the calculations to calculate stream concentrations of cypermethrin where the farmyard was the source. In this study, runoff from a farmyard was monitored continuously from July 2006 to September 2006 during which time there were two dipping events. The mass of cypermethrin removed from the farmyard during natural rain events (and an irrigation event after the first dip due to the very dry weather) was monitored as was the stream into which the runoff flowed (sampling station 300 m downstream from the farmyard).

Farmyard discharge was monitored every minute, and a composite sample of runoff was taken every 15 minutes. The composite sample consisted of three consecutive samples taken every 5 minutes being placed into a single vessel. The mass of cypermethrin removed from the farmyard was determined by first calculating a mass of cypermethrin at each minute by linear interpolation of concentrations between two successive 15-minute sampling points, and multiplying this estimated concentration by the measured discharge at each minute. Stream discharge was measured every 5 minutes. The mass of cypermethrin removed from the farmyard in 5 minutes was calculated by summation. This mass was divided by the total stream water volume discharged in 5 minutes to give a 5-minute average concentration of cypermethrin in the stream. These data were used to calculate hourly average concentrations during the event, i.e. when there was runoff from the farmyard, and a 24-h maximum time-weighted average concentration (TWAC). The estimated values for each event are given in Table 3. These are based on dilution alone and they do not account for any dissipation that may occur between the farmyard and the stream and/or within the stream.

Table 3 PECs due to farmyard losses based on dilution alone

Per event						1-h TWAC (ng/L)			24-h TWAC
Date	Duration (h:min)	Total mass removed* (ng)	Total stream volume (L)	Average conc. (ng/L)	Maximum conc. (ng/L)	1st hour	2nd hour	3rd hour	Max. (ng/L)
02/08/06	1: 29	141,975	38,534	3.68	71.14	10.56	0.01	-	0.03
18/08/06	1: 40	765,836	207,581	3.69	17.82	6.41	0.07	-	0.71
21/08/06	2: 13	26,572	43,458	0.61	3.98	1.19	0.27	0.08	0.02
27/08/06	3:30	353,475	208,040	1.70	40.35	0.05	6.61	0.23	0.27
02/09/06	7:46	16,412,214	5,937,433	2.76	70.22	36.96	22.99	1.24	1.38

02 Sept. 06 TWA for hours 4-8 were 0.14, 0.12, 0.60, 0.06, & 0 ng/L respectively.

*Although the accuracy of the data may not warrant 8 significant figures, the data remain unchanged from the actual values calculated (mass x discharge) in order to maintain transparency.

There were only two positive detections of cypermethrin in the stream in study VM02502: 198 ng L^{-1} from the 27 August 2006 event and 92 ng L^{-1} during the 2 September 2006 event. These measured concentrations are both higher than the maximum predicted concentration, although that from 2 September 2006 is a similar order of magnitude to the maximum predicted concentration. The high maximum event concentration for the first event, but low 24 h maximum TWA, is attributable to the low stream discharge when there was runoff from the farmyard (< 3 L s^{-1}) with the maximum discharge during the event (~ 15 L s^{-1}) not occurring until runoff had almost ceased.

4.3 Comparison of exposure routes

A simple comparison of the relative importance of the different sources of exposure (farmyard vs in-pasture) was made by comparing the total mass of cypermethrin removed from the farmyard in VM0205 to that removed from the fleece of the sheep (Section 3). The mass of cypermethrin from the farmyard (Table 3) was divided by the mass removed from the fleece after different drying times in order to calculate the number of sheep required to equal farmyard losses during the different rain events. The results are shown in Table 4.

Table 4 The number of sheep for the quantity of cypermethrin removed from fleece (1 – 28 DAT) to equal losses from the farmyard for individual rain events

Farmyard cypermethrin (ng)		141,975	765,836	26,572	353,475	16,412,214
Cypermethrin per sheep (ng)	Days since dipping	02/08/06	18/08/06	21/08/06	27/08/06	02/09/06
508000	1	0.28	1.51	0.05	0.70	32
590000	2	0.24	1.30	0.05	0.60	28
494000	3	0.29	1.55	0.05	0.72	33
234000	7	0.61	3.27	0.11	1.51	70
107000	14	1.33	7.16	0.25	3.30	153
54000	21	2.63	14.18	0.49	6.55	304
55000	28	2.58	13.92	0.48	6.43	298

With the exception of the large storm event of 2 September 2006, very few sheep (and a realistic number) need enter the stream for the cypermethrin loss to be equivalent to that from the farmyard, highlighting the significance of ‘in-pasture’ as an exposure route.

This basic assessment provides some indication of the order of magnitude of cypermethrin concentrations and how they may vary in the stream during storm events. However, cypermethrin is a lipophilic compound and has a propensity for binding to sediment. Existing models for predicting the environmental concentration of pesticides were used to predict cypermethrin concentrations in streams when accounting for dissipation and are described in the following section.

4.4 Modelling Predicted Environmental Concentrations

There must be a pollutant source, an initial mobilisation of the pollutant and a means via which it is transported to water bodies in order for water contamination to occur. Predicting the environmental concentration of a pollutant requires an understanding of these different components. Many decades of research have increased the understanding of the fate and behaviour of agricultural pesticides, and models have been developed to predict environmental concentrations under different agricultural scenarios (e.g. FOCUS, 2001). The accuracy of the predicted environmental concentrations (PECs) is dependent on the accuracy of the data used to describe the processes that occur in the environment. Given i) the importance of sheep entering the stream as an exposure route, ii) the absence of data available to describe the fate and behaviour of sheep dips from their source to a water course, and iii) the natural variability in scenarios that occurs in the field (e.g. distance from farmyard to water course *cf* edge of field in cropped land), in this study, work was directed towards describing in-stream processes in order to predict concentrations when accounting for dissipation, and the TOXSWA model was adapted to an upland sheep farm scenario.

The TOXSWA model was originally developed to calculate exposure concentrations in surface water for the ecotoxicological risk assessment of pesticides (Adriaanse, 1996). The model simulates the behaviour of a pesticide in surface water bodies such as ditches, streams and ponds following input of pesticides via drainage, runoff or spray drift from an adjacent field. The model calculates hourly pesticide concentrations in both the water phase and the sediment of the water body and it is based on the following processes:

(i) Transport - pesticides are transported downstream with the water flow in the water layer.

(ii) Transformation - transformation takes place in the water and in the sediment. The transformation rate considers the combined effects of hydrolysis, photolysis and biodegradation and it is a function of temperature. Exchange with the sediment layer takes place by diffusion.

(iii) Sorption – both the organic fraction in the sediment and suspended particles in the water layer offer sorption sites.

(iv) Volatilisation – is a function of temperature.

In the current study, FOCUS_TOXSWA version 2.2.1 (Beltman et al., 2006) was used. Cypermethrin is released into the stream at a single inlet point and it is diluted with the water in the stream where some of the compound adsorbs on suspended solids and sediment. Distribution of the compound between the water and sediment takes place by diffusion into and from the sediment. Sorption to the sediment, and dissipation of cypermethrin in the water body and in the sediment are calculated separately. Dissolved cypermethrin and suspended solids are transported down the stream with the flowing water. The stream is divided into segments (Section 4.4.1) through which water enters and exits on an hourly basis, with dynamics occurring every 10 minutes, and the output of TOXSWA is an hourly PEC in both the water and the sediment for a single segment in the stream. The pollutant is exposed to a single segment over one hour with clean water flowing into the first segment and contaminated water flowing out. A PEC can be calculated for each individual segment, but, for the purposes of this study, only the PECs for the first segment are given as this will be the most contaminated part of the stream and therefore represent a worst-case scenario. The release of the pollutant to the stream over one hour is a limitation of TOXSWA for the purposes of the current study. Whilst this will not affect time weighted average concentrations, it is likely to affect the maximum PEC and TOXSWA may underestimate the maximum PEC in a sheep farm scenario. This should be taken into consideration when interpreting the results.

4.4.1 Sheep farm scenario

As TOXSWA is an ‘in-stream’ model, the sheep farm scenario is dependent on the definition of an upland stream and three scenarios were selected representing a small, medium, and large upland stream. Data for the small stream were taken from the previous VMD study (VM02502). The stream was referred to as Woolley Beck to ensure anonymity. Data for the medium and large stream scenarios were selected from data provided by the Environment Agency for a number of upland streams in North Yorkshire Dales, Yorkshire Moors and North Pennines. Table 5 shows the average flow rates in the selected streams monitored over 1999 to 2007. There is a higher probability that sheep will enter streams during warm weather when stream levels are typically low (Section 4.1), thus the lowest stream flow rates (July and August, which also coincides with dipping season) were used in the simulations. From a risk management point of view, this also provides a worst-case scenario.

Table 5. Average stream flow rates for the three upland stream scenarios

Scenario	Stream name	Approx. altitude (m)	Average flow rate (m^3/day)	Average flow rate in Jul/Aug (m^3/day)
Small	Woolley Beck	300		2335[a]
Medium	Hebden Beck	230	16576[b]	8690[b]
Large	Trout Beck	540	49785[b]	32633[b]

[a]Average from July -August 2006 only [b]Averages from 1999 to 2007

The stream was divided into 10 segments of 10 m each. The bottom width of the stream was 1 m and the sides of the stream bed were sloped at an angle of 30° (Figure 4). The height of the water in the TOXSWA model was constant and dependent on the flow rate: 12.9 cm for small, 20.3 cm for medium and 32.4 cm for the large stream scenario.

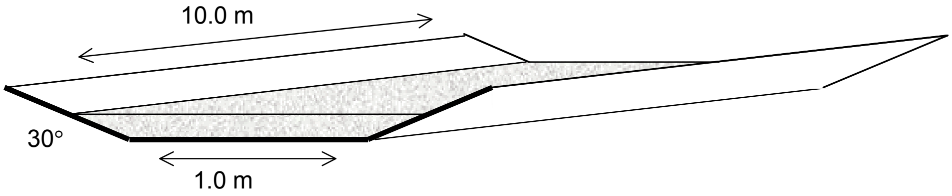

Figure 4. Dimensions of the stream

Attempts were made to reduce the length of the segment, but the model would not then function at high flow rates (i.e. the large stream scenario). The effect of decreasing the size of the segment was investigated on a small stream (i.e. low flow rate) and the difference in results using 5m or 10m segments was negligible.

Other characteristics of the stream were identical to those used for FOCUS (2001) (Table 6) with the exception of sediment that was assumed to be only 2 cm deep. Sediment in upland streams is likely to shallow i.e. ≤ 2 cm. However, sediment depth does not significantly affect the model outcome because a) partitioning occurs in the surface of the sediment, and b) partitioning to the sediment is much less relevant than flow rate in determining PECs in an upland stream. The depth of sediment layer did not influence the total amount of cypermethrin that partitioned to the sediment. This was confirmed in additional model simulations (results not shown).

Table 6 Sediment & suspended soil characteristics of FOCUS water bodies

Concentration of suspended solids in water column (mg/L)	15
Sediment layer depth (cm)	5
Organic carbon content of sediment (%)	5
Dry bulk density (kg/m3)	800
Porosity (%)	60

Data source: FOCUS (2001)

4.4.2 Sorption and degradation in the stream

Degradation of cypermethrin in the stream is dependent on the temperature. The literature was examined in order to establish typical upland stream temperatures in summer in the UK (Table 7). Stream temperatures in Scotland were a few degrees lower than those in England and Wales, as could be expected due to the latitude. For the purposes of this study, stream temperatures in England and Wales were used and the average summer stream temperature was a constant 15°C. Additional model runs using temperatures of 12°C and 18°C showed that temperature did not significantly affect PECs (Appendix 12.3).

Table 7 Summer stream temperatures for upland streams in the UK

Stream	Region	Approximate summer temperature (°C) Mean	 Range	Years	Data source
Girnock Burn	Aberdeenshire	12.5	11 to 13.5	1968 - 1997	Langan et al 2001
River Pulham	Exmoor	14*	12.5 to 16*	1976 - 2004	Webb et al., 2008
Afon Hafren & Afon Hore	Plymlinon	15*	10 to 20*	1985 - 1990	Neal et al., 1992

* Read from graph

Sorption and degradation are a function of the physico-chemical properties of a compound. Cypermethrin is non-polar, has a very low solubility in water, and is extremely hydrophobic so it will rapidly partition from the water to suspended particles and sediment, where it is strongly adsorbed (Muir et al., 1985; Agnihorti et al., 1986; Laskowski, 2002; Frieberg-Jensen, 2003). In TOXSWA, sorption to suspended particles in the water phase and the bottom sediment is calcuated separeatly and it is a function of the sorption coefficient for binding to organic carbon (K_{OC}). The sorption coefficient for cypermethrin has been determined for several soil types and it ranges between 2.65 $x10^4$ and 1.45 $x10^5$ L/kg (European Commission, 2005). The average value of the reported K_{OC} range was used in the model for the Freundlich sorption coefficient normalised for organic carbon content. The Freundlich exponent was set to the default value of 0.9. The quantity of cypermethrin associated with suspended sediment is reported as part of the water-PEC.

In the water-sediment system degradation is expected to occur mainly in the sediment phase. Degradation is assumed to be negligible in water as cypermethrin is expected to be stable in water under normal environmental temperatures and pH (Walker & Keith, 1992). The degradation half-life for water was therefore set to 1000 days (negligibly slow degradation). This approach is expected to give conservative estimates for PEC values in the stream. The vapour pressure of cypermethrin is very small, hence no volatilisation of cypermethrin is expected. A summary of the parameters that were used in the model to describe the behaviour of cypermethrin in the stream is given in Table 8.

Table 8. Sorption and degradation properties for cypermethrin in the stream

Molecular mass (g/mol)	416.3
Vapour pressure at 20 ºC (Pa)[1]	$2.3 \cdot 10^{-7}$
Solubility in water at 20 ºC (mg/L)[2]	$4 \cdot 10^{-3}$
Sorption coefficient K_{OC} (L/kg)[1,3]	85,572
Freundlich exponent	0.9
DT50 for degradation in water at 20 ºC (days)	1000
DT50 for degradation in sediment at 20 ºC (days)	17

[1] European Commision, 2005; [2] Kollman and Segawa, 1995
[3] Average from K_{OC} range 26492-144652 L/kg

4.4.3 In-pasture exposure scenario

The permutation of scenarios of sheep entering the stream is numerous and it depends on the number of sheep entering the stream at one time, the frequency of entry per day, the number of days when the stream is entered and whether or not these days are consecutive. This is in addition to the fact that the stream size will influence the resulting concentration. A number of contrasting scenarios were selected in order to demonstrate the impact on cypermethrin concentrations of different sheep numbers and the frequency of entering different sized streams. The scenarios used were:

- One, ten or 300 sheep entering a small, medium, or large stream, 1, 14 or 28 days after treatment; for these scenarios the *measured* cypermethrin quantities were used as input values (Table 10 Section 3).
- One or ten sheep entering a small stream on a daily basis; for these scenarios the quantity of cypermethrin entering the stream each day was estimated from a fitted curve (Figure 5).

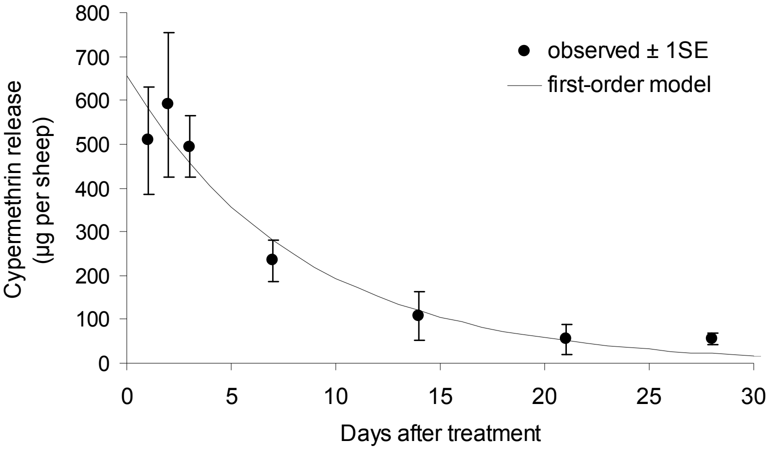

Figure 5 First-order curve fitted to measured data of cypermethrin removed from sheep entering a simulated stream at different days after treatment.

4.4.4 Farmyard exposure

Cypermethrin can only be removed from the farmyard during rain events, thus the stream into which the runoff will flow is not expected to have constant flow and it will respond to rainfall (*cf* in-pasture exposure). The PEC resulting from discharge from the farmyard was calculated using actual hourly flow rates for the stream. Inputs of cypermethrin to the stream were taken from VM02502, calculated from the average of two successive sampling points and summing the values to give an accumulated mass of cypermethrin entering the stream every hour.

The stream was divided into 20 segments of 5 m each – this was possible as a small stream was used. The bottom width of the stream was 1 m and the stream banks were sloped at an angle of 30° (Figure 4). The height of water in the stream fluctuated depending on the flow rate in the stream. The variation of the water level in time was calculated by assuming a backwater curve in front of a weir (Beltman et al., 2006). For the upland stream the height of the weir was set at the minimum value of 10 cm and the distance to the weir was 500 m.

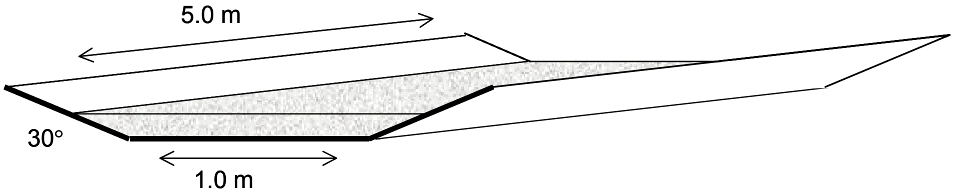

Figure 6. Dimensions of the stream into which farmyard runoff discharged

Hourly data from the monitored streams were used as input for the simulations (data source: VM02502 and Environment Agency). The monitored data showed large fluctuations in flow rate, thus a base flow of 300 L/h was assumed to allow the model to accommodate the strong fluctuation. Any values below the base flow rate were adjusted to equal the base flow rate. Besides this adjustment, the flow rates in the simulation were identical to the measured flow rate. A comparison of the predicted stream flow versus measured stream flow is provided in the appendix (12.4).

5 TOXSWA RESULTS

5.1 Sheep entering the sheep on one occasion

Water and sediment PECs for one, ten or 300 sheep entering a small, medium, or large stream at 1 day, 14 days or 28 days after treatment (DAT) were calculated. The results for one sheep entering a small stream 1 day after treatment are discussed below as an illustration, before presenting the results for all other scenarios. Figure 7 shows the concentration in water and sediment of a small stream following one sheep entering the stream one day after treatment.

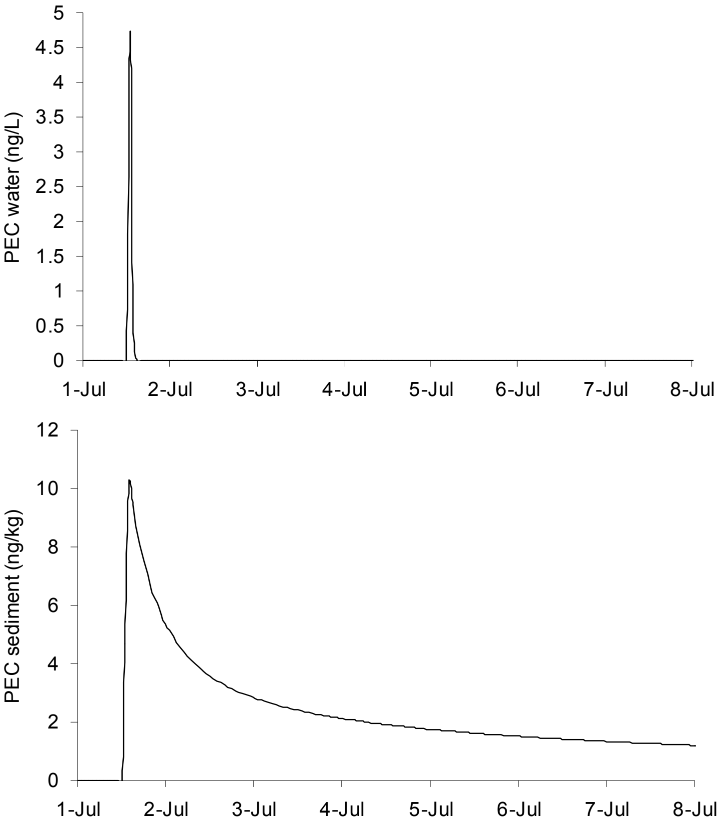

Figure 7. Predicted cypermethrin concentrations in the water and sediment of a small stream following one sheep entering the stream at midday on 1 July.

The cypermethrin removed from the sheep (508 μg) was released into the water over a period of 1 hour. The concentration in water reached a maximum level of 4.7 ng/L, but the majority of the compound (>99%) was rapidly transported away with the downstream flow and concentrations were reduced to 0.4 ng/L within one hour and < 0.006 ng/L after two hours. Approximately 0.3% of the cypermethrin partitioned into the sediment. The concentration in the sediment reached a maximum of 10.2 ng/kg (based on dry weight). The concentration in sediment declined slowly, partly due to degradation of the cypermethrin but mainly due to diffusion back into the water. This diffusion back into the water phase was not matched by any concurrent increase in cypermethrin in the water phase due to the rapid throughflow of water distributing the compound downstream. Consequently, after the initial input, water concentrations continued to decline despite inputs via diffusion.

At the maximum (water) concentration, 23% of the cypermethrin in water was associated with suspended particles in the stream. This percentage increased when the concentration in water declined. The maximum PEC values in water and bottom sediment for all scenarios are summarised in Table 9. As could be expected, PEC values in water were directly proportional to the number of sheep entering the stream and the concentrations were highly dependent on the size of the stream so the PEC values in water were at least 10 times smaller in the large stream than in the small stream.

Table 9. PEC values for water and bottom sediment in the small, medium and large stream following one, ten or 300 sheep entering the stream on a single occasion, either 1 day, 14 days or 28 days after treatment of the sheep.

Number of sheep	Days after treatment	PEC water (ng/L)			PEC sediment (ng/kg)		
		Small stream	Medium stream	Large stream	Small stream	Medium stream	Large stream
1	1	4.7	1.3	0.4	10.2	4.1	1.4
1	14	1.0	0.3	<0.1	2.1	0.8	0.3
1	28	0.5	0.1	<0.1	1.1	0.4	0.1
10	1	47.3	13.0	3.6	104.3	41.9	14.7
10	14	10.0	2.7	0.7	21.7	8.7	3.0
10	28	5.1	1.4	0.4	11.1	4.4	1.5
300	1	1419.4	390.1	106.6	3149.4	1279.4	454.8
300	14	299.0	82.2	22.5	663.8	268.3	94.9
300	28	153.7	42.2	11.5	340.5	137.4	48.5

The pattern of PECs was the same for all scenarios where the sheep entered on a single occasion, i.e. an initial peak followed by a rapid decline. Although even just one sheep can cause a PEC > 2 ng/L in a small stream, the concentration had declined to < 0.4 ng/L within an hour. The decline in concentrations from the peak for the different scenarios is provided in Figure 8 and Figure 9 to illustrate the time required for the PEC to reduce to < 0.1 ng/L. The figures illustrate that there is a very rapid decline in PECs in the first two hours since the sheep entered the stream. Even when 300 sheep entered the stream just one day after dipping the PEC was < 2 ng/L within 4 hours, but it took over 24 hours for the PEC to decline to < 0.1 ng/L.

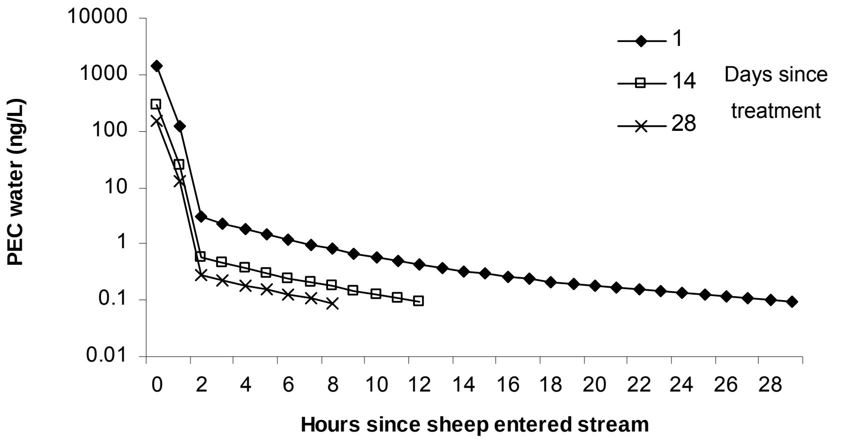

Figure 8 The decline in PEC with time for 300 sheep

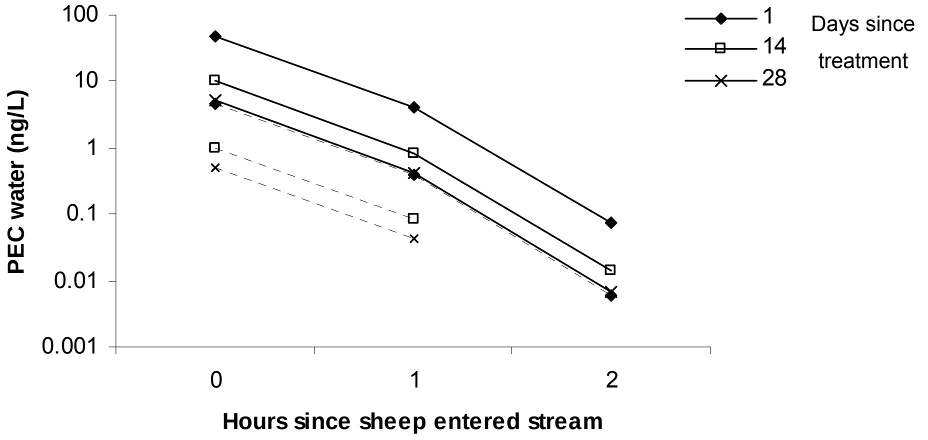

Figure 9 The decline in PEC with time for 1 sheep (dotted line) and 10 sheep (solid line)

The 6-hour and 24-hour time-weighted average concentrations (TWAC) in water and sediment were calculated by averaging the actual concentration over 6 hours and 24 hours respectively. Table 10 and Table 11 show the 6-hour and 24-hour TWAC values for all scenarios. As could be expected, TWAC values were lower than the maximum PECs reflecting the fact that the peak concentration is short-lived. In the large stream, water TWACs were < 1 ng/L for up to ten sheep even if the sheep entered 1 day after treatment.

Table 10. 6-hour TWAC values for water and bottom sediment in the small, medium and large stream following one, ten or 300 sheep entering the stream on a single occasion, either 1 day, 14 days or 28 days after treatment of the sheep.

Number of sheep	Days after treatment	6-h TWAC water (ng/L)			6-h TWAC sediment (ng/kg)		
		Small stream	Medium stream	Large stream	Small stream	Medium stream	Large stream
1	1	0.9	0.2	<0.1	8.5	3.5	1.2
1	14	0.2	<0.1	<0.1	1.8	0.7	0.3
1	28	<0.1	<0.1	<0.1	0.9	0.4	0.1
10	1	8.6	2.3	0.6	83.4	34.2	12.3
10	14	1.8	0.5	0.1	17.9	7.3	2.6
10	28	0.9	0.3	<0.1	9.2	3.7	1.3
300	1	258.0	69.5	18.5	2346.3	976.6	355.7
300	14	54.3	14.6	3.9	511.5	211.5	76.5
300	28	27.9	7.5	2.0	266.1	109.8	39.6

Table 11. 24-hour TWAC values for water and bottom sediment in the small, medium and large stream following one, ten or 300 sheep entering the stream on a single occasion, either 1 day, 14 days or 28 days after treatment of the sheep.

Number of sheep	Days after treatment	24-h TWAC water (ng/L)			24-h TWAC sediment (ng/kg)		
		Small stream	Medium stream	Large stream	Small stream	Medium stream	Large stream
1	1	0.2	<0.1	<0.1	5.7	2.4	0.9
1	14	<0.1	<0.1	<0.1	1.2	0.5	0.2
1	28	<0.1	<0.1	<0.1	0.6	0.3	<0.1
10	1	2.2	0.6	0.2	53.6	22.5	8.3
10	14	0.5	0.1	<0.1	11.8	4.9	1.8
10	28	0.2	<0.1	<0.1	6.2	2.6	0.9
300	1	64.8	17.4	4.6	1441.9	609.1	226.1
300	14	13.6	3.7	1.0	320.3	134.8	49.8
300	28	7.0	1.9	0.5	168.2	70.7	26.1

5.2 Sheep entering the stream on a daily basis

Concentrations in the stream and in bottom sediment were calculated for one or ten sheep entering the stream on a daily basis for a period of up to 28 days after dipping. The quantity available for removal on each individual day was calculated from the first-order curve (Figure 5). It should be noted that the current study did not quantify successive removal from an individual sheep, thus the results below necessarily assume a different sheep enters the water each day.

Figure 10 shows the hourly concentrations in the water and bottom sediment of a small stream for ten sheep entering daily. The concentration in water is strongly influenced by the day since treatment, and the maximum water concentration occurs on the first day after treatment (54.2 ng/L). However, in the bottom sediment, the accumulation of cypermethrin is apparent and sediment concentrations reach a maximum on the fourth day (149 ng/kg).

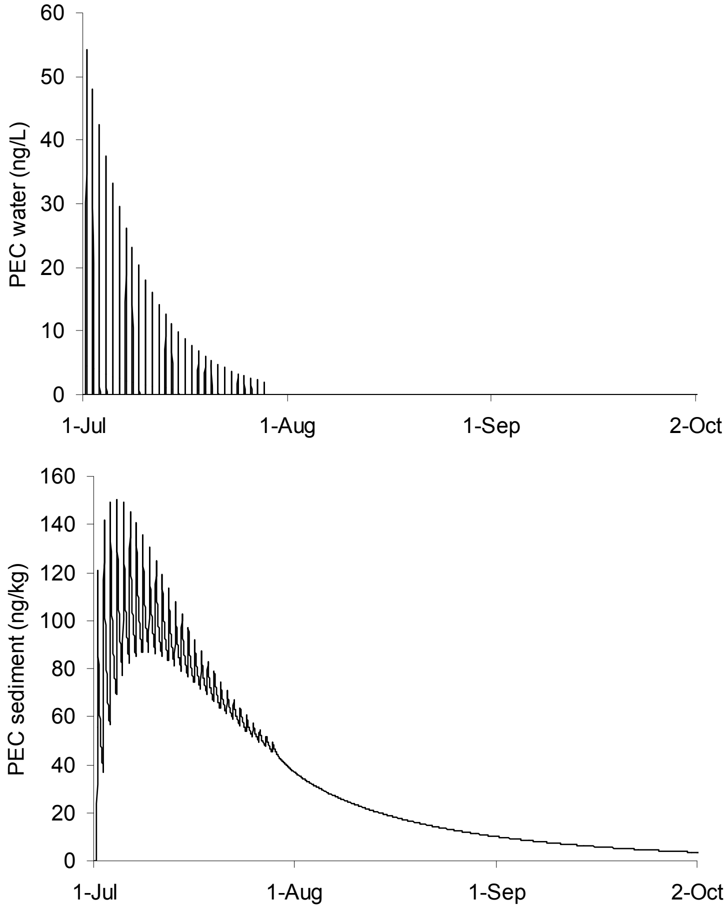

Figure 10. Predicted environmental concentrations in the water and sediment of a small stream following ten sheep entering the stream daily for 28 days where Day 1 = day after dipping.

Figure 11 shows the 24-hour time weighted average concentrations (TWAC) for water and sediment of a small stream when ten sheep enter daily. The maximum TWAC in water (2.47 ng/L) occurred on the first day, and the maximum TWAC in sediment (105 ng/L) was reached on the seventh day.

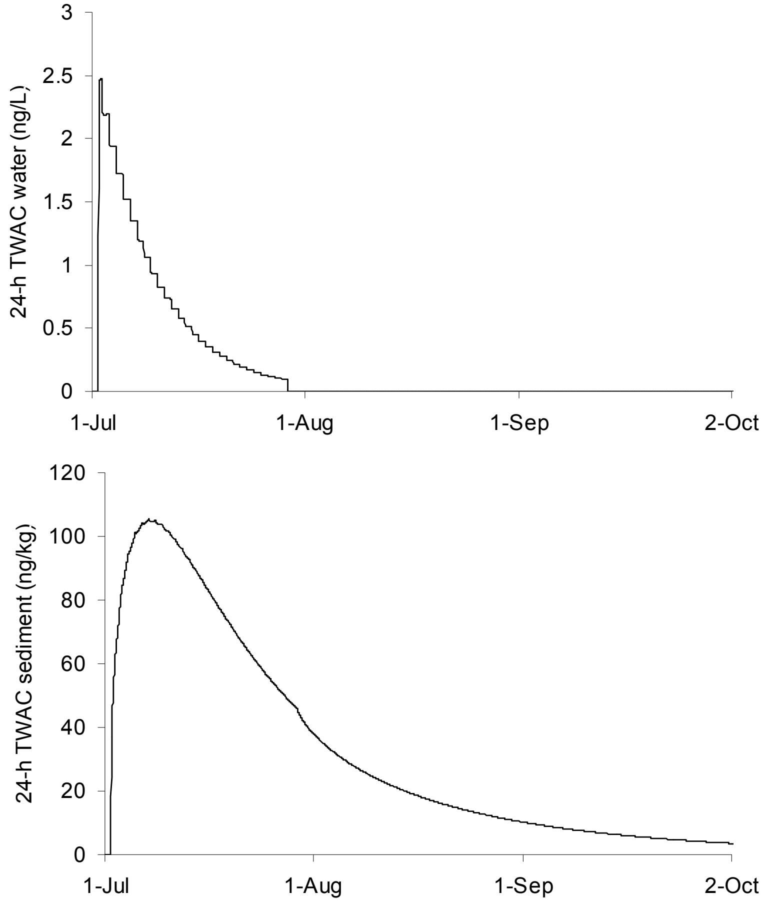

Figure 11. 24-hour time weighted average concentrations (TWAC) in the water and sediment of a small stream following ten sheep entering the stream daily for 28 days.

The maximum PECs for all scenarios are summarised in Table 12. Note that the PEC values are similar to the PEC values listed in Table 9 for sheep entering a stream on a single occasion one day after treatment. The PEC values in Table 12 are however larger because the amount of cypermethrin that was released per sheep on day 1 was slightly higher in these simulations due to the curve fitting (see section 4.4.1). Outputs of the 6- and 24-h TWACs are given in the appendix (12.5).

Table 12. Maximum PEC values for water and sediment in the small, medium and large stream following 1 or 10 sheep entering the stream on a daily basis for 28-days after treatment.

Number of sheep	PEC water (ng/L)			PEC sediment (ng/kg)		
	Small stream	Medium stream	Large stream	Small stream	Medium stream	Large stream
1	5.4	1.5	0.4	15.4	6.3	2.3
10	54.2	14.9	4.1	149.4	61.5	22.2

5.3 Farmyard exposure

Cypermethrin concentrations in the water phase and the bottom sediment of the stream resulting from runoff from the farmyard are presented for July through to October. Cypermethrin inputs were dependent on data from VM02502 which was monitored from July to September. The PECs are modelled for a further month to accommodate any persistence. The PEC and 24h-TWAC for both the water and sediment phase are provided in Figure 12 and Figure 13 (note the difference in scales).

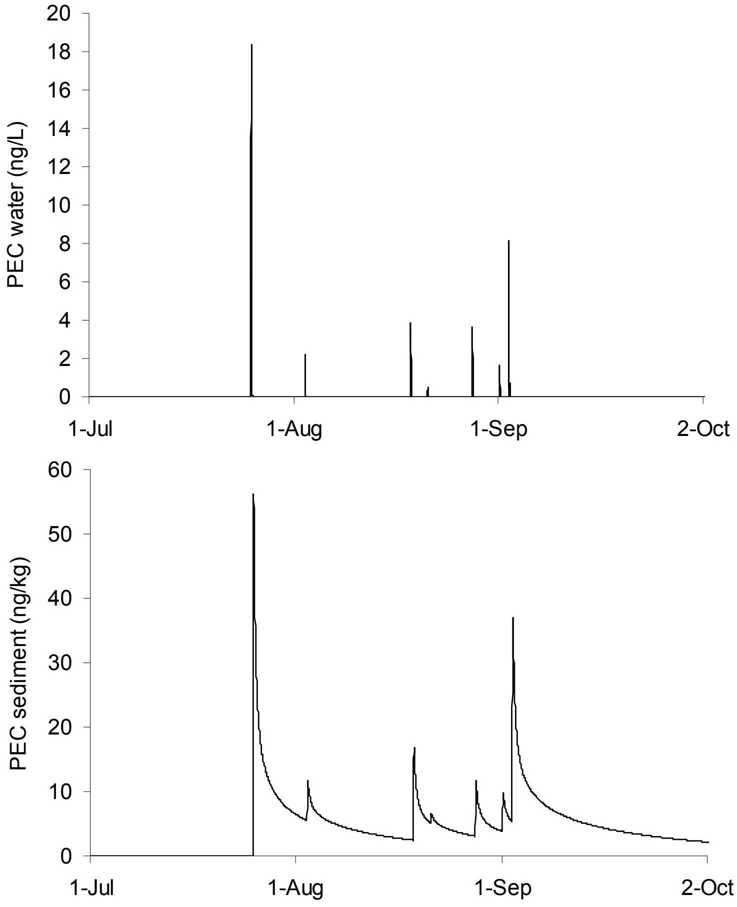

Figure 12 Predicted cypermethrin concentrations in the water phase and bottom sediment arising from farmyard losses

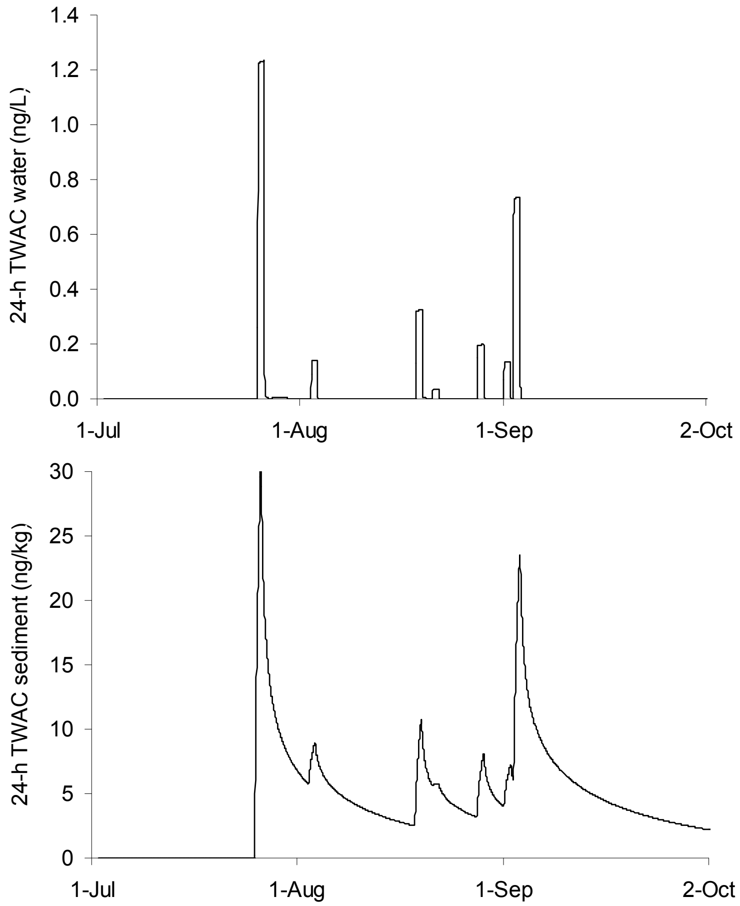

Figure 13 Cypermethrin 24h time weighted average concentrations arising from farmyard losses

Cypermethrin concentrations are short-lived in the water phase as illustrated by the rapid decline in the PEC, and the much lower 24 h-TWAC compared to the peak concentrations – 24h-TWACs were ten times lower than the maximum PECs. This compares to concentrations in the sediment that are not even halved when comparing the 24h-TWAC to the maximum PEC. This effect is due to the rapid throughflow of clean water and the downstream migration of cypermethrin. Comparison of the TOXSWA-PECs for farmyard losses and those from dilution alone (Section 4.2) reveal slight differences. This may be due to some differences in the approaches, for example the PECs in Section 4.2 were calculated on 5-minute intervals, whereas in TOXSWA, processes occurred on a 10-minute time-step and input is averaged over one hour. There are also some sorption losses to sediment in TOXSWA (although these were very small compared the effect of flowrate).

5.4 Environmental relevance

The environmental relevance of the PECs depends on how they compare to appropriate thresholds within the legal framework. The Water Framework Directive (WFD) has been set at the EU-level with the aim of achieving a good level of water quality for all rivers, lakes, estuaries, coastal water, and groundwater in the European Union by 2015. This has been transposed into UK law, and a series of measures have been, and are continuing to be developed to aid implementation of the WFD. Environmental Quality Standards (EQSs) are part of the approach used to monitor water quality. For cypermethrin, the Maximum Allowable Concentration (MAC) is 0.002 µg L^{-1} (2 ng L^{-1}) and the Annual Average (AA) is 0.2 ng L^{-1}. However, these EQSs are currently under review and the proposed[4] long-term predicted no effect concentration (PNEC) is 0.1 ng L^{-1} and 0.4 ng L^{-1} for short-term exposure. (It should be noted that whilst these are potentially equivalent to the EQS, MAC and AA respectively, it is not yet confirmed whether this approach of using the PNEC as an EQS is acceptable).

The data in Table 9 (maximum PEC values) indicate that there is a high probability that the current MAC (2 ng/L) will be exceeded in a small stream as the likelihood of only a single sheep entering the stream is low, and the proposed potential 'MAC' (0.4 ng/L) could be exceeded in a large stream with at least 10 sheep even when 28 days have lapsed since dipping. However, the peak concentrations of cypermethrin are very short-lived and, using the 24-h TWAC as a guide – which will provide an overly conservative estimate – the annual average in a large stream is unlikely to be exceeded unless a (small) flock enters the water. However, in a small stream it is possible that the AA could be exceeded. This is more so if the threshold is reduced to 0.1 ng/L.

The water quality standards discussed above provide thresholds that are a legal requirement. These thresholds consider the toxicity of compounds to flora and fauna, and the low MAC and AA reflect the high toxicity of cypermethrin to aquatic organisms. Examples of the toxicity are provided in the appendix for information (12.6), and are not discussed in the main body of the report, as it is the MAC and AA that are the legal benchmark against which PECs should be compared. Many of the toxicity studies conducted were on time-scales of several hours to days and so do not accurately reflect exposure scenarios relevant to sheep dip pollution via sheep entering a stream, i.e. on a very short time scale and/or where there is a rapid flow of water. The levels at which cypermethrin can be toxic to organisms are also very close to the limit of detection when analysing water concentrations, thus establishing accurate measures of toxicity can be difficult.

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[4] EA Science Report SC040038/SR7

5.5 Environment Agency Pollution Incidents

It was initially proposed to re-evaluate pollution incidents identified by the Environment Agency in light of the findings of the current study in an attempt to elucidate the probable cause of the incident. However, this was not possible with the level of detail available. Cypermethrin concentrations in EA moss samples were in the order of 1 – 2 ug/kg which, if sorption can be considered to be the same as to sediment, is comparable to a flock of sheep having entered the stream when comparing this to the TOXSWA results. Maximum levels of cypermethrin in the EA Pesticide Monitoring Report for 2003 (i.e. before suspension of the licence) were in the order of 2 – 30 ng/L. Again, using the modelling results, it would be feasible that these concentrations may arise from either a small number of sheep that had been dipped within the last 2 weeks entering the stream and/or a field of sheep entering on a daily basis, i.e **these concentrations may be possible without the misuse of the product.**

6 POST-DIPPING PRACTICES

Farmers in England and Wales were visited to ascertain their post-dipping practices. Areas visited included Powys (6), North Yorkshire (2), Cumbria (5), NW Wales (2), Devon (4) and Northumberland (5). Sheep dipping is a sensitive issue and contacts were obtained through the National Farming Union and the Farming Union for Wales. It is therefore possible that these farmers represent 'best' practice – only one farm was not in some form of agri-environment scheme (e.g. Entry/Higher Level Stewardship, Tir Gofal) - and this should be considered when interpreting results. Some of the farmers were visited alongside an Environment Agency officer during groundwater authorisation (GWA) inspections, so, similarly, some of the replies may have been guarded. However, there was no reason to believe the answers were not representative of the individual's practices. In total 30 farms were visited, but only 24 comprehensive results were obtained.

6.1 Sheep dipping operations

Ewe flock sizes varied from 140 (Dartmoor) to 2050 (Skipton) with an average ewe flock size of 918 (median = 865). Half the farmers dipped twice a year (summer and autumn) and half dipped only once a year. Of those dipping once a year, half (n = 5) dipped in autumn, a third dipped in summer (n = 3) and the remainder dipped in late summer/early autumn. Over 90% (n = 22) of the farmers used organophosphates (OPs) (primarily Osmonds Gold Fleece) and only two farmers exclusively used synthetic pyrethroid (SP) as their dip of preference. Many cited that OPs were more efficacious than SPs; those using SPs stated that OPs made them ill/for health reasons – as did a farmer who still used OPs; one farmer commented that SPs made him ill. Only 3 farmers (13%) used an additional product at the time of dipping (purl, zinc, blume) and two mixed this with the dip as they thought it enhanced the performance of the dip. Only 2 (8%) farmers did not use an additional form of treatment such as pour-ons or injections. (Although the majority of farmers in this study used OPs it is worth considering that those who cannot use OPs on health grounds may have been forced to use an alternative treatment to plunge dipping, thus there may be an unavoidable bias).

All farmers with static dippers had a groundwater authorisation licence (or it was being applied for; n = 1) with the exception of one farmer - he dipped the smaller animals last to reduce the need to top up and then used the dip remaining (~ 100L) to disinfect the shed. Only three farmers emptied the bath immediately and/or on the same day. Most (n =13) left the dip in the bath for a few days before getting round to disposing of it, although this was longer for 2 farmers (2 weeks – 1 month). Only one farmer used a contractor and another who had a shower and therefore low volumes of waste (~ 30 L), stored the spent dip in containers. Only 2 farmers did not dilute the spent dip before spreading it to land, otherwise it was diluted with water, slurry, or manure.

Sheep were generally kept from half an hour to a few hours before dipping although some were brought in overnight. None of the dipping areas were normally covered with the exception of one farm who used a mobile shower in a barn. All the mobile units had a single drip pen, as did two of the static plunge dippers, but, on the whole, the farms had double drip pens. All the static drip pens drained back into the bath. The length of time spent dripping varied from less than 5 minutes for the shower units (n=4) to two hours (n=1). Excluding these farms, standard drip times ranged from 10 to 30 mins. Half the farmers thought the drip time could not be increased whilst half thought it could with 30 minutes being the most commonly cited maximum drip time where there was room for an increase. Contamination of the drip pen, and hence the dip bath, was voiced as the main reason for not increasing the drip time further. (Farmer-opinion on drip times are considered in more detail in Section 7.2).

6.1.1 Post-dripping

After dipping and dripping, a third of farmers released the sheep to a field (n=8), 2 farmers kept the animals in a barn. Standing on concrete after dripping was only required at 3 farms, although, for two of these some sheep were also kept in fields. On one farm, the post-drip area drained to the bath and the water was collected in a storage tank. The remaining farmers (n=9) released the animals to the farmyard/hardcore. Only 4 farms collected runoff from the farmyard otherwise the water could soak through the ground or runoff with the exception of 2 farms that dipped/showered in the field.

The time between dripping and being released to pasture varied greatly from 0.5 h to overnight. One farmer kept sheep in the drip area for 1 to 5 h before turning them into a field without access to a watercourse and then released them to the hills 24 hours after that; one kept them for at least 48 hours away from water, but aimed for 1 week, and two kept them for 1 to 2 days before releasing them to pasture – all these farmers had to cross a stream to return their sheep to pasture. Less than half (n = 11) released the sheep to pasture after less than 2 h post-dripping. For the remaining farms, release times ranged from 3 h to overnight.

Thirty percent of farmers (n=7) needed to cross a stream to return the sheep to pasture, but over 90% (n=22) of farms had watercourses in pasture. It was generally commented that sheep farming country and surface watercourses went hand-in-hand, with only a few exceptions. Approximately 60% of farms (n=16) needed to use a road as a route back to pasture, although this was only to cross the width of the road in 4 cases and distances were generally < half a mile. Five farmers also used a trailer with all of them washing them down – 1 in the field, 2 on the farmyard with no waste collection and 2 on the farmyard with drainage to the slurry pit.

7 Management Options

Any management option intended to reduce the impact of sheep dips on the environment must be entirely practicable to be adopted on a scale that will ultimately benefit the environment. Sheep dipping is a time-consuming practice involving a great deal of physical exertion and as many sheep as possible are dipped in a single day. Management options must therefore not interfere excessively with the dipping process and it should be affordable.

7.1 Removal of excess dip immediately after dipping

Removing excess dip from the feet of the sheep was considered a potential option, as this would involve no extra cost, or that of some shampoo, assuming farmers already own a footbath. However, this technique did not significantly reduce the quantity of cypermethrin available for removal when fording a stream (Section 3).

7.2 Environment Agency options

The Environment Agency has considered eight options for controlling the use of cypermethrin sheep dips. These are given below with feedback from farmers on the feasibility/usefulness of the option.

1. Dip operator to hold NPTC Certificate of Competence (CoC) parts 1-3.

This was not a popular option on the whole as all farmers questioned had been dipping for years and therefore did not need practical experience and it was seen as just more red tape. Nearly 70% (n =13) of farmers disagreed with this and some farmers found the suggestion insulting. However, of those who did disagree with it, ~ 40% suggested that it could be beneficial for younger farmers who had not had the same experience.

2. Farmer to have a groundwater authorisation, or proof of suitable alternative disposal arrangements.

There was a 50:50 split on those farmers who agreed with this (although the answer was generally an acceptance “ok”, rather than “yes, I agree”). Those farmers who did not agree with it saw it as just more red tape. Other comments included, “it’s not worth the paper it’s written on”; “it won’t address issues” and there were several complaints that a fee is paid on an annual basis for a groundwater authorisation licence even though nothing changes.

3. Location of dip > 100m from watercourse or water source

Although most farmers (70%, n =14) disagreed with this as a generic statement, there were suggestions that it could apply to new facilities, and/or farms should be considered individually and the distance then defined by the risk. One farmer commented that there was no evidence that ‘100 m’ was safe and that this was a backdoor to banning dipping. For all those farmers who agreed with the comment, the distance from their bath to surface water was at least 100 m. In the current study, over 60% of the dipping facilities were distanced at least 100 m away from surface water.

4. Minimum containment of 2 drip pens & to afford 20-30 min drip time per pen for all sheep.

There was a general consensus that farmers already tried to retain as much dip as possible in the bath so they didn't have to replenish it as often, thus saving themselves both time and money. Most farmers (80%; n = 16) therefore agreed with this statement as they believed they already complied with it (the data show that although they had 2 drip pens, they did not necessarily drip them for 20-30 min). Some farmers who agreed with the double drip pen, thought that a drip time of 20-30 min was unnecessarily long as it was the first few minutes that were of more relevance. Moreover, the longer the sheep stayed in the drip pen, the more contaminated it becomes with faeces and urine, and it is for this reason that farmers did not want to extend the drip time. The faeces/urine reduces the effectiveness of the dip and one respondent proposed that persons may then be more tempted to increase the strength of the dip solution in order to ensure efficacy, thus negating the 'benefit' of the increased dripping time. Some farmers have designed their dipping facilities so the liquid draining away from the drip pen flows via a sump which can collect faecal matter before it drains back to the bath. **This could be an option to consider for future improvements.** Farmers disagreeing with this statement did not have a double drip pen and two commented that substantial capital investment would be required.

Other dis-benefits of extending the drip time include a reduction in the number of sheep that can be dipped in a day which could be costly (e.g. labour costs, replenishing the dip, and possibly feed costs). Knock-on effects could include where to hold the sheep prior to and after dipping – if all the sheep have to be held on land near the farm both before and after dipping this could pose difficulties for keeping treated and untreated sheep separately and/or there may not be sufficient pasture so food may have to be supplied – if this is dry, it would increase the probability of the sheep subsequently going to water to drink. Holding the sheep for longer in high densities also increases stress to the animal.

One farmer suggested that, for those farmers who did not already have a double drip pen, it is highly probable that many would, very practically, divide the current drip pen in half. There may be a tendency to dip a similar number of sheep and squeeze them into the smaller space, thus there is very little space available for the sheep to shake. The concept of shaking vs dripping is not one that has previously been considered and it was mentioned by other farmers. It seems reasonable to propose that more excess dip will be removed from a sheep that shakes its fleece compared to sheep that simply drip, although in the summer months there may be less difference, as the fleece length is short.

It is possible therefore that, in practice, advocating a double drip pen with no overall assessment of the dipping facility may not provide any environmental benefit.

The absence of any evidence to support this proposed mitigation option was an issue to the farmers.

5. Collection pens prior to dipping associated with new dipping facilities

On the understanding that this meant having the facilities to ensure that all sheep were gathered prior to dipping so no treated and untreated sheep mixed in pasture, only one farmer (who had new dipping facilities) agreed with this comment. The general consensus was that every attempt was made to ensure that all sheep to be dipped were as it was a waste of time to mix dipped and undipped sheep. However, it was also commented that on large farms with dispersed pasture it was physically impossible to be sure that every single sheep was rounded up – if a sheep had strayed off, you wouldn't know it was missing. If collection pens were required, other problems may arise when trying to keep different hefts and/or 'fields' of sheep apart. There may be a practical reason why sheep are kept in certain groups and they are not necessarily grouped by equal numbers. This could therefore be difficult to accommodate for in collection pens requiring the pens to be constantly changed to accommodate different sheep numbers.

6. Sheep contained in holding paddock for 24, 48, (or 72) hours post dipping, with no access to a watercourse

There were mixed views on this depending on the layout of the farm. Only 20% (n =4) agreed with this statement. Some farmers did keep the sheep away from water for 24 hours where their pasture allowed and they were very clear on their responsibilities for doing this. However, on the whole, anything longer than 24 hours was seen as wholly impractical as there wasn't sufficient pasture to accommodate the sheep for so long and on upland, hill farms there may not be sufficient land suitable to enable this. Feed would have to be bought (at expense) to supplement the diet due to lack of pasture and, if this was dry, then there would be a higher probability of a sheep subsequently entering a stream to drink. It is also possible that poaching could be an issue, particularly in autumn, if a large number of animals are kept on a limited area of land. The cost of piping in water would also be an issue. Again, erosion around watering troughs could be significant given the large number of animals. A further issue may be that of mixing hefts as discussed in option 5.

7. Fencing to restrict sheep access to watercourses and no requirement to cross a watercourse when returning to normal pasture after dipping.

On the whole, the idea of fencing watercourses was seen as totally impractical and on some common land (e.g. National Park, MOD) it would be prohibited by the landowner. Fencing watercourses on lower-lying land may be possible but in all cases capital grants would be necessary not only for the fencing, but also for piping the water. Mains water does not always exist, thus the expense of the infrastructure required could be substantial – there could also be a significant cost in getting fencing and/or piped water materials to the areas where they were need (e.g. by helicopter) in order to avoid damaging the soil and vegetation. In boggy areas it would difficult to define where the land ended and the watercourse started. Another concern with fencing was the loss of Single Farm Payment (SFP). Assuming that some grazing land would necessarily be fenced off in order to protect the stream, on land where there were a large number of small streams, the total land lost could be significant in terms of SFP.

Bridges over watercourses is a management option that farmers believed was physically possible, but the costs involved could be prohibitively high. Whilst it would be necessary to ‘train’ the sheep to go over the bridge by shepherding, this should only require a few runs before the sheep would then choose the bridge as the preferred route across the stream as long as though there was no alternative. Some farmers were of the opinion that even if a bridge was built, if a sheep wanted to cross the stream without using the bridge and it could, it would. It may therefore be necessary to support the infrastructure with some fencing or similar to block off any adjacent areas where the sheep could physically cross increasing, thus the cost of this option. The evidence provided by the current study with regards to the quantity of dip removed for up to 4 weeks after treatment would provide valuable support to the mitigation option of “no fording watercourses when returning the sheep to pasture”. The evidence could be used to demonstrate the necessity of ensuring NO sheep enter water soon after dipping and thus support the need to also ensure stream banks adjacent to the bridge are fenced where necessary.

There was a common consensus that sheep generally avoided water when they could and they wouldn’t enter streams with any significant flow unless they were forced through – this may either be by the farmer, or if people or dogs are in the same field (whilst the sheep may not necessarily be chased, they will choose flight as their means of escape, thus dogs/people being in the same field may sufficient for them to take flight. **The definition of a watercourse and/or understanding how a sheep may contaminate water may require clarification to assist in reducing pollution**. A number of farmers referred to ‘gutters’ that would normally flow only in the wet and these were not necessarily considered to be a watercourse.

8. No use of cypermethrin dips in showers and jetters as they are not an approved use for these products.

Only 15 % (n = 3) farmers agreed with this statement and there was a greater range in responses for this option than for other options, including: it was up to the user to decide whether it suited their use; they should be approved; I don't use SPs; impossible to enforce; SPs are no good anyway.

7.3 Co-ordinated dipping

The incidence of scab is more prevalent on common grazing land (HCC, 2007) as treated sheep can mix with untreated sheep. The same situation can arise on enclosed land where neighbouring farms do not treat sheep at a similar times. This was apparent from farm visits in the current study, for example, some farmers did not have to dip sheep that were not grazed on common land; others were exasperated with their neighbours. A scab control programme in south-east Scotland has demonstrated the effectiveness of a co-ordinated approach in geographically distinct areas (Heriot and Pentland hills). This initiative involved inviting farmers to meetings (by word of mouth, letter and peer pressure) which involved education about sheep scab, clarification and information on different treatment options and defining a plan of action. There were no cases of sheep scab within the control area although there were numerous cases elsewhere.

Double fencing could be an option to reduce transmission of scab between farms, but there are costs of fencing and loss of land, and there may be more effective management options.

7.4 Catchment Sensitive Farming (CSF)

On the environmental side, initiatives such as the English Catchment Sensitive Farming Directive Initiative (ECSFDI) and/or the Voluntary Initiative could be used (and are in some areas) to ensure dipping sites are suitable to specific locations within each water catchment. Such an approach could complement a co-ordinated dipping programme to reduce the effort involved with getting farmer engagement, which is of paramount importance to the success of such initiatives. The CSF approach has proved popular with those involved, with the very practical advice tailored to individual situations and financial support being a key part of its success (Defra, 2008).

The meetings/workshops could also be used to identify why farmers do things in certain ways, thus creating a two-way educational process between catchment officers and the farmers.

7.5 Cypermethrin-approved farms

It is possible that the dipping facilities and pasture properties on some farms are such that the probability of a pollution incident occurring is very low. Such a farm would typically have no access to surface water in pasture, and there would be no surface hydrological connection to watercourses (taking account of slope, distance to watercourse, landcover, soil type). Under these circumstances cypermethrin may be used without undue risk to the environment. This would entail individual assessments of each farm. Any assessment could have a tiered approach so that in Tier 1 an overview of the dipping facilities is obtained, e.g. the farmer provides details of his dipping facilities layout, where water drains to when not dipping, drains and watercourses in the vicinity of the farm and on pasture, and details of where sheep source their water from. Unsuitable farms could be identified and any farms that appeared suitable on paper could be followed up by a visit to verify the claims.

Such an approach would need to be complemented by a mechanism whereby the sale of cypermethrin dips was very restricted. (This would also reduce any off-label usage of the compound). This approach may be difficult to police.

This could be incorporated with the CSF and/or co-ordinated dipping approach.

7.6 Empty containers

It has been noted that the farmyard is a source of agricultural pesticides where the originating source may be, for example, upturned pesticide containers, drips from sprayers, contaminated sprayers returning to the yard, or the cleaning of sprayers. There was a common consensus that used sheep dip containers were thoroughly rinsed with the rinsings going into the bath, i.e. there was no waste of the dip due to its high cost. Upturned containers are unlikely to be a source of sheep dip on the farm.

7.7 Farmyard layout

It could be expected that the main source of dip from the farmyard arises from the dipping operation and sheep standing on the yard. Whilst all drip pens should drain to the bath (and this is the case in the majority of farms), the holding area where the sheep stand after being released from the drip pen does not have to drain back to the bath, although farmers are encouraged to ensure that the area does contain soil or grass (i.e. organic matter that could adsorb the sheep dip and limit leaching); the Environment Agency is encouraging new dipping apparatus to include a second holding area that drains back to the bath.

All static baths viewed in this study were ‘uncovered’ (i.e. there was no permanent structure over the dip bath or the dipping areas), although they would be covered with e.g. metal sheeting. This sheeting would not prevent water from the drip pens draining into the bath and it is feasible that baths fill up with rainwater when not in use. Indeed some facilities have a sump that allow the water from the drip area to be diverted away from the bath when it is not in use in order to prevent it filling up with rainwater. It is not known what the ‘out-of-season’ sheep dip concentrations of bath water would be, but this could be significant for baths situated close to watercourses. In order to encourage farmers to address this, it may be necessary to provide real data on actual concentrations that may be associated with rain-filled baths.

7.8 Landguard

Although not applicable to cypermethrin products, Landguard has the potential to assist in reducing pollution from sheep dips and it is considered here briefly. Landguard is an enzyme-based product that degrades diazinon to < 99% of the initial concentration within a few hours when added to the spent dip (unpublished data). This could therefore reduce pollution from the farmyard and also any potential contamination arising from during spreading to land (although this may be small compared to losses from the farmyard). It is possible that there may be scope in the future for Landguard to be applied more widely across drip and post-drip holding areas, but a) this method has not been field-tested and b) there will be cost implications.

7.9 Summary

Options for reducing pollution from sheep in pasture are very limited and keeping sheep away from surface water at all times is not practical on the whole, and is likely to be very expensive. There may be some individual cases where this could be achieved.

A flock of sheep fording a stream, even several weeks after dipping, could cause a pollution incident. Building bridges and installing and fencing to negate this is likely to be expensive, but it is feasible. This option could be considered on a case-to-case basis. The data from the current study could provide the evidence that such measures are required.

Co-ordinated treatment with neighbours has the potential to reduce scab and may reduce the number of dips required - other forms of treatment may be suitable (although withdrawal times may be an issue). This would require substantial support from appropriate personnel, but a Scottish study has demonstrated that this approach has great potential. Such an approach could be complemented by environmental initiatives such as CSF, which have also proved successful.

8 DISCUSSION

The field study has provided solid evidence that cypermethrin may still be retained within the fleece for several weeks after dipping and that this may subsequently be removed if a sheep fords water. Losses can be substantial within the first week after dipping and, although they steadily decline, the quantities removed are still environmentally relevant even 4 weeks after dipping. The modelling has demonstrated that, as could be expected, there is a large variation in predicted concentrations of cypermethrin depending on the stream size, the number of sheep involved and the days since dipping.

It has been established that sheep entering water is likely to be a greater risk than farmyard losses, thus defining the behaviour of sheep is fundamental to defining the risk of cypermethrin. There was a general consensus that sheep do not like water and they will certainly not enter fast flowing streams voluntarily. The primary reasons for sheep entering water were to drink during hot weather and during lactation, and to get to grazing on the other side – through choice, or if frightened. There are however no hard data on the probability of sheep entering a stream, nor the length of time they may remain there. It was therefore necessary to generate contrasting scenarios for TOXSWA. Although these were arbitrary, they were also realistic - the average flock size in Less Favoured Areas (LFA) in the UK is ~ 475 and 244 in non-LFA (GHK, 2007). With regard to the length of time the sheep may spend in the stream, in the field study this did differ, so the results obtained the quantity of dip removed can account for some of the variation that may occur in reality; most sheep ran through the water, but no sheep were in there for more than a few minutes. There is the potential therefore that more cypermethrin may be removed if the sheep stay in water for longer, but assuming that sheep do not enter water for more than a few minutes to drink, then the current study reasonably covers time spent in the stream. The exposure scenarios detailed in Section 4 are therefore unlikely to over-estimate PECs and can be considered realistic. If anything, the upper figure of 300 sheep used in the TOXSWA calculations may underestimate maximum PECs - the purpose of the data was to illustrate the range in PECs that could be expected. Similarly, the hourly time-steps in TOXSWA may underestimate the maximum PECs, but it is considered that, given the uncertainties in sheep behaviour, on the whole this model provides a good indication of PECs that could be expected under a range of scenarios. Even given these limitations, the closeness of the EQSs to the PECs for such a small number of sheep indicates that there is a reasonable possibility that the EQS will be exceeded in a small stream, particularly if less than two weeks have lapsed since dipping. If an entire flock enters a stream, there is a high probability that the EQS will be exceeded even in a large upland stream (mean low flow rate ~ 0.34 cumecs).

The TOXSWA model demonstrated that cypermethrin concentrations were likely to decline rapidly from the initial peak. Although cypermethrin will rapidly bind to sediment, in the scenarios considered here, the decline in concentration was primarily due to the inflow of clean water, and bottom sediment is not generally expected in upland and/or fast flowing streams. Further downstream, it could be expected that sediment thickness increases slightly, but it is unlikely to increase to greater than 2 cm in sheep-farming territory, and the current model accommodates for this depth of sediment. Moreover, it was interesting to note that relatively more cypermethrin was associated with the suspended solids and therefore remained in the water phase than partitioned to the bottom sediment. As the TOXSWA model predicts concentrations in a 'segment' of water, the pollutant moves down successive segments so that whilst there was a decline in the PEC in the first segment the pollutant would simply move into the adjacent segment as it was the flow rate that was driving the PEC. TOXSWA is not designed to accurately describe PECs downstream from discrete pesticide inputs, but, as an indication, PECs in the segment 90 – 100 m downstream, PECs were only 2% less than that in the first segment.

Several of the farmers in this study were aware of their responsibility to keep sheep out of water for 24 hours after dipping and they took action to keep sheep away from water even longer if they had to ford a stream on the return to pasture. However, the results of this study have indicated that significant quantities can still be removed even two weeks after dipping. Keeping sheep away from watercourses for up to 3 days was seen as impractical by many farmers and the majority would not be able to use a product if it was necessary to keep sheep out of watercourses at all times.

The lack of evidence to support guidance on sheep dipping practices was a moot point for many farmers. Until now there was no evidence to support the length of time to keep sheep away from water, but those farmers visited were supportive of the quantitative nature of the work. There was little support for the 20 – 30 minute drip time (as discussed in Section 7.2) and the lack of evidence to support this guidance was considered a weakness; some thought it would be the first few minutes that counted more. It is possible that it is more important to ensure that all sheep receive a 10 minute drip time – if a small number of sheep drip for only a few minutes, the quantity of dip subsequently removed in the post-drip area (e.g. between 3 and 10 minutes) could far outweigh that removed between 20 and 30 minutes. Sheep shaking after exiting the dip bath may also reduce the quantity of dip remaining on the fleece. **These factors would need quantifying to provide evidence to support any guidance**.

The results of this study have demonstrated that even if the farmer was following current guidance, there is the potential for cypermethrin concentrations in streams to exceed the EQS. A farmer could therefore be prosecuted when using the product in good faith. However, this study has necessarily assumed that good agricultural practice is being applied and it does not account for all situations. For example, the proximity of some baths to watercourses is concerning, some drip areas/holdings areas have a bung (which could consist of an old rag) that allows water to be diverted away from the bath (to prevent it overflowing) when not dipping, thus runoff from the drip areas can drain to watercourses. It is therefore possible that it is bad practice that has caused some of the pollution incidents monitored by the Environment Agency, although there remains a real possibility that use rather than mis-use could also cause pollution.

Similarly, losses from the farmyard could be greater if holding pens are made of concrete, rather than hardcore, as in study VM02502 on which this current study is based, although no farms in the current study had wholly concrete areas as their post-drip area, but concrete adjacent to hardcore could form some of the post-drip area. In addition, this study has not considered drips and spills of pour-ons onto the farmyard, but the quantities of solution involved are much less than that for plunge dipping, thus environmental risks associated with pour-ons should be lower than with dipping.

8.1 Other observations

Mobile dips and showers were more apparent in the current study than VM0205. A limitation of these is the very small drip pen and the short dripping time. Whilst they have the advantage that they can be taken into the field and dipping can occur on grass away from watercourses, only one farm actually did this with other farmers still dipping in the yard. In these situations the mobile dipper has the potential to be more polluting as the drip time is so short and any drips from the dipper do not drain into a single place.

Several farmers quoted that they knew SPs were 200 times more toxic than OPs, but OPs stuck to the soil more. It was notable that there was consistency in the ‘200 times’ more toxic indicating that the source of the information was probably the same. More concerning was the impression that OPs were less mobile than SPs. If OPs are considered to be less toxic and less mobile, then it ‘follows’ that they are less harmful to the environment. It may be prudent to ensure that there is a clear message that OPs are highly damaging to the environment and can cause, and have caused pollution incidents. Messages such as “with the correct use and disposal, organophosphate products (diazinon) are safe and degrade in the environment” (British Veterinary Association, 2006[5]) are very concerning, particularly as it has been shown that word-of-mouth was an important mechanism for engaging with farmers in ECSFDI (Defra, 2008). It may be more appropriate to say OPs ‘present a lower risk than cypermethrin’ than they are ‘safe’.

Farmers raised the issue of withdrawal periods for other treatment methods such as injectables and highlighted that it was not that simple to replace one treatment method with another.

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[5] Annex: Consultation on the draft pollution reduction programme of sheep dip: Responses in Full.

9 CONCLUSIONS

- Losses from fleece were significantly lower when the drying time was increased from 1 to 2 weeks and from 2 to 3 weeks.

- There was no significant decrease in losses when the drying time increased from 3 to 4 weeks despite 80 mm of rain.

- Cypermethrin losses after 4 weeks were in the order of 55,000 ng per sheep in 100 L of water.

- Running the sheep through a footbath of either water or shampoo after dipping did not significantly reduce the quantity of cypermethrin subsequently available for removal when fording a stream.

- There is a high probability that a flock of sheep (~ 300) entering any size stream up to a summer flow of ~ 0.34 cumecs will cause sufficient pollution to exceed the MAC even 4 weeks after dipping based on the TOXSWA modelling.

- There is a high probability that a small number of sheep (< 10) entering a small upland stream (flow ~ 0.03 cumecs) 24 hours after dipping could cause sufficient pollution to exceed the MAC based on the TOXSWA modelling.

- Farmers in this study were aware of the need to keep dipped sheep away from surface water for 24 hours after dipping, but in many cases it was seen as not practical to keep them away from streams for longer than this.

- 30% of farmers needed to cross streams to return to pasture; of these, over half kept their sheep out of water for at least 24 h – some for longer.

- Over 90% of farms had surface water in pasture.

- Most farmers did not believe that a drip time of 20 to 30 minutes would necessarily be beneficial to the environment - there was no evidence for this.

- All farmers disposing of their dip to land had a groundwater authorisation licence.

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11 ACKNOWLEDGEMENTS

The authors are grateful to Cross Vetpharm for the supply of test compound, in particular Karen and Stephen for expediting this at very short notice, and Evans Vanodine International for the supply of shampoo. The authors are also indebted to Trish for assistance in preparing the ATC and Anne. We would also like to thank Katja and Melanie for assistance with field work and the farmer and his assistant for their co-operation. The authors are also indebted to all the farmers who provided information on their dipping practices and the NFU, FUW and an Environment Agency Officer for assistance with gaining contacts.

12 APPENDIX

12.1 Raw data

Sample No.	cypermethrin in sample (μg/L)	cypermethrin in control (μg/L)	GC-MSD sequence No.	Final volume (mL)	r^2 value	Treatment	Replicate	Kept?	Day
21	14.44	<0.033	211107	0.1	0.9976	W	1	out	1
22	13.93	<0.033	211107	0.1	0.9976	W	2	out	1
23	12.89	<0.033	211107	0.1	0.9976	S	1	out	1
24	31.47	<0.033	211107	0.1	0.9976	S	2	out	1
25	9.53	<0.033	211107	0.1	0.9976	W	1	in	1
26	13.70	<0.033	211107	0.1	0.9976	S	3	out	1
27	12.72	<0.033	211107	0.1	0.9976	W	2	in	1
28	10.89	<0.033	211107	0.1	0.9976	W	3	out	1
29	6.96	<0.033	211107	0.1	0.9990	W	3	in	1
30	5.77	<0.033	211107	0.1	0.9990	C	1	in	1
31	59.03	<0.033	211107	0.1	0.9990	C	2	in	1
32	16.45	<0.033	211107	0.1	0.9990	C	1	out	1
33	12.35	<0.033	211107	0.1	0.9990	C	2	out	1
34	8.95	<0.033	211107	0.1	0.9990	C	3	in	1
35	11.15	<0.033	211107	0.1	0.9990	C	3	out	1
36	25.48	<0.033	211107	0.1	0.9990	S	1	out	2
37	12.90	<0.169	06122007	0.1	0.9986	W	1	out	2
38	4.33	<0.169	06122007	0.1	0.9986	W	1	in	2
39	9.32*	<0.169	06122007	0.1	0.9986	W	2	out	2
40	34.27	<0.169	06122007	0.1	0.9986	W	3	out	2
41	20.64	<0.169	06122007	0.1	0.9986	S	2	out	2
42	3.00	<0.169	06122007	0.1	0.9986	W	2	in	2
43	22.80	<0.169	06122007	0.1	0.9986	S	3	out	2
44	4.75	<0.169	06122007	0.1	0.9986	W	3	in	2
45	11.97	<0.169	06122007	0.1	0.9974	C	1	out	2
46	12.77	<0.169	06122007	0.1	0.9974	C	2	out	2
47	9.14	<0.169	06122007	0.1	0.9974	C	3	out	2
48	10.15	<0.169	06122007	0.1	0.9974	C	1	in	2
49	6.65	<0.169	06122007	0.1	0.9974	C	2	in	2
50	18.57	<0.169	06122007	0.1	0.9974	C	3	in	2
51	12.33	<0.169	06122007	0.1	0.9974	W	1	out	3
52	17.46	<0.169	06122007	0.1	0.9974	W	2	out	3
53	14.62	<0.169	06122007	0.1	0.9974	W	3	out	3
54	10.03	<0.169	06122007	0.1	0.9974	S	1	out	3
55	19.48	<0.169	06122007	0.1	0.9938	S	2	out	3
56	17.60	<0.169	06122007	0.1	0.9938	S	3	out	3
57	10.61	<0.169	06122007	0.1	0.9938	C	1	out	3
58	12.17	<0.169	06122007	0.1	0.9938	C	2	out	3

59	18.96	<0.169	06122007	0.1	0.9938	C	3	out	3
60	6.42	<0.169	06122007	0.1	0.9938	W	1	out	7
61	8.84	<0.169	06122007	0.1	0.9938	W	2	out	7
62	7.95	<0.169	06122007	0.1	0.9938	W	3	out	7
63	5.95	<0.169	06122007	0.1	0.9938	S	1	out	7
64	3.26	<0.169	06122007	0.1	0.9938	S	2	out	7
65	5.54	<0.169	06122007	0.1	0.9989	S	3	out	7
66	11.07	<0.169	06122007	0.1	0.9989	C	1	out	7
67	4.98	<0.017	15012008	0.1	0.9970	C	2	out	7
68	9.18	<0.017	15012008	0.1	0.9970	C	3	out	7
69	10.42	<0.033	15012008	0.2	0.9970	C	1	out	14
72	1.60	<0.033	15012008	0.2	0.9970	S	1	out	14
73	1.67	<0.033	15012008	0.2	0.9970	S	2	out	14
74	2.08	<0.033	15012008	0.2	0.9970	S	3	out	14
75	3.19	<0.033	15012008	0.2	0.9970	W	1	out	14
76	0.76	<0.033	15012008	0.2	0.9977	W	2	out	14
77	2.19	<0.033	15012008	0.2	0.9977	W	3	out	14
80	2.96	<0.033	15012008	0.2	0.9977	C	2	out	14
81	4.00	<0.033	15012008	0.2	0.9977	C	3	out	14
82	0.58	<0.033	15012008	0.2	0.9977	W	1	out	21
83	1.89	<0.033	15012008	0.2	0.9977	W	2	out	21
84	0.43	<0.033	15012008	0.2	0.9977	W	3	out	21
85	5.86	<0.033	15012008	0.2	0.9977	S	1	out	21
86	2.17	<0.033	15012008	0.2	0.9977	S	2	out	21
87	0.47	<0.033	15012008	0.2	0.9987	S	3	out	21
88	1.86	<0.033	15012008	0.2	0.9987	C	1	out	21
89	0.54	<0.033	15012008	0.2	0.9987	C	2	out	21
90	0.78	<0.033	15012008	0.2	0.9987	C	3	out	21
91	2.09	<0.033	15012008	0.2	0.9987	S	4	out	28
92	2.57**	<0.033	15012008	0.2	0.9987	S	5	out	28
93	1.21	<0.033	15012008	0.2	0.9987	S	6	out	28
94	1.28	<0.033	15012008	0.2	0.9987	W	7	out	28
95	0.67	<0.033	15012008	0.2	0.9987	W	8	out	28
96	1.41	<0.033	15012008	0.2	0.9987	W	9	out	28
97	2.25	<0.033	15012008	0.2	0.9995	C	10	out	28
98	2.51	<0.033	15012008	0.2	0.9995	C	11	out	28
99	0.94	<0.033	15012008	0.2	0.9995	C	12	out	28

* Only two sheep **One sheep went through 3 times!

C = control W = water S = shampoo

12.2 Recovery Tests

Target mass (mg)	Measured concentration (µg/L)	mg in 100L	% recovery	Average recovery %
4	40.03	4.003	100	
4	37.61	3.761	94	**97**
4	38.51	3.851	96	
0.2	1.37	0.137	69	
0.2	1.25	0.125	63	**66**
0.2	1.34	0.134	67	

There is no obvious explanation for differences in the recoveries. Any minor error in the preparation of the stock solution that was added to the bath, or the analysis of the samples, would be magnified for the lower concentration. Nevertheless, the majority of actual samples were at concentrations above the target mass of 0.2 mg, thus the recovery was greater than 60%, and this should be taken into consideration in the interpretation of the data.

12.3 The effect of temperature on PEC

It was expected that temperature would not significantly affect PECs as degradation, which can be affected by temperature, was negligible. A limited number of model runs were conducted to test this theory. The results are presented below comparing the maximum PEC and the TWAC for three temperatures and two scenarios. Temperature did not affect water concentrations of cypermethrin. There was a slight decrease in sediment-PEC with a temperature increase of 3°C but this was < 1%.

	10 sheep daily			**300 sheep 1 DAT**		
	12°C	**15°C**	**18°C**	**12°C**	**15°C**	**18°C**
Dissolved concentrations in water (ng/L)						
max	45.8	45.8	45.8	1255.3	1255.3	1255.3
6-h TWAC	8.3	8.3	8.3	227.5	227.5	227.5
12-h TWAC	4.2	4.2	4.2	114.0	114.0	114.0
24-h TWAC	2.1	2.1	2.1	57.1	57.1	57.1
Total concentrations in water (ng/L)						
max	54.2	54.2	54.2	1419.4	1419.4	1419.4
6-h TWAC	9.8	9.8	9.8	258.0	258.0	258.0
12-h TWAC	4.9	4.9	4.9	129.4	129.4	129.4
24-h TWAC	2.5	2.5	2.5	64.8	64.8	64.8
Concentrations in sediment (ng/kg)						
max	150.1	149.4	148.4	3150.0	3149.4	3148.8
6-h TWAC	132.0	130.9	129.6	2348.1	2346.3	2344.3
12-h TWAC	120.2	119.0	117.6	1893.9	1891.8	1889.3
24-h TWAC	106.8	105.3	103.6	1445.0	1441.9	1438.2

12.4 Monitored vs predicted streamflow data used in TOXSWA for farmyard exposure

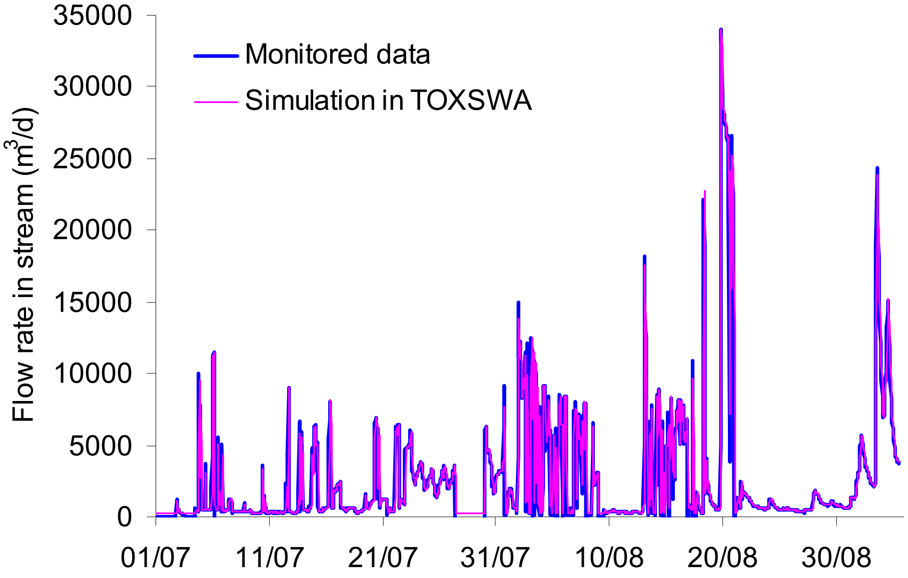

Figure 14. Monitored and simulated flow rates in the upland stream

12.5 6- and 24-h TWACs from sheep entering the stream on a daily basis

Table 13. 6-hour TWAC values for water and sediment in the small, medium and large stream following one or ten sheep entering the stream on a daily basis during a 28-day period after treatment.

Number of sheep	6-h TWAC water (ng/L)			6-h TWAC sediment (ng/kg)		
	Small stream	Medium stream	Large stream	Small stream	Medium stream	Large stream
1	0.98	0.26	0.07	13.84	5.74	2.09
10	9.83	2.65	0.71	130.93	54.58	19.99

Table 14. 24-hour TWAC values for water and sediment in the small, medium and large stream following one or ten sheep entering the stream on a daily basis during a 28-day period after treatment.

Number of sheep	24-h TWAC water (ng/L)			24-h TWAC sediment (ng/kg)		
	Small stream	Medium stream	Large stream	Small stream	Medium stream	Large stream
1	0.25	0.07	0.02	11.34	4.75	1.75
10	2.47	0.66	0.18	105.34	44.33	16.41

12.6 Toxicity of cypermethrin to aquatic organisms

Data from the literature provided information on the toxicity of cypermethrin to aquatic organisms. There have been several studies investigating a wide range of effects on different organisms using a range in concentrations of cypermethrin and several studies have demonstrated that a cypermethrin concentration of 100 ng/L is sufficient to have an effect or cause death (Morolli et al., 2006; Moore & Waring, 2001; Jaensson et al., 2007; Christensen et al., 2005). However, a number of studies have also shown that much lower cypermethrin concentrations are of relevance. Moore and Waring (2001) reported that nominal concentrations as low as 10 ng/L could significantly affect the priming response of males to the pheromone F-type prostaglandin, $PGF_{2\alpha}$ – expressible milt quantities were lower when fish were exposed to cypermethrin. Plasma testosterone and plasma 17,20βP were not affected until cypermethrin concentrations were between 50 and 100 ng/L – there was no significant effect at 50 ng/L, but there was at 100ng/L. A nominal concentration of 10 ng/L could also significantly reduce the olfactory detection of $PGF_{2\alpha}$. (Although the paper reports the aforementioned responses as occurring at concentrations of < 4 ng/L, the target concentration in the tests that this refers to was 10 ng/L. At then end of the 5-day test, a water sample was analysed for the cypermethrin concentration and this returned a value of < 4 ng/L; 4 ng/L being the LOD. The authors state that they did not have data regarding water concentrations earlier in the exposure period, thus acknowledging that this terminal concentration does not necessarily reflect the concentration during the study. It may be more accurate to assume that the fish were exposed to the entire quantity of cypermethrin that was added to give a concentration of 10 ng/L – whilst this may have subsequently declined, it is not possible to state whether the cypermethrin sorbed to the fish, or other parts of the test system. Moreover, the paper illustrates a significant difference in two test groups (nominal concentrations of 1 and 10 ng/L) that are both reported as having a concentration of 4 ng/L. In the absence of data to verify the actual concentration of the test system during the study, it may be more accurate to assume that the quantity added was the quantity that the fish were exposed to, hence the use of nominal concentrations in the current study – whichever the actual concentration, the most important issue is that it is very low.

Other researchers have also demonstrated effects on aquatic organisms at relatively low concentrations. Wendt-Rasch et al (2003) calculated no effect concentrations (NOEC) of 10 ng/L and an LC_{50} of 50 ng/L in a 4 hour test for *nauplii* (crustacean larvae) and an LC_{50} of 50 ng/L or less for *Daphnia cucullata* for a period of 1 – 11 days – the data are based on estimated cypermethrin concentrations (discussed in Friberg-Jensen et al., 2002) as the nominal concentrations were so close to the limit of detection. Hill (1985) cited in Clark et al (1987) similarly reports a 96 hr LC_{50} of 50 ng/L for *Mysidopsis bahia* (mysid shrimp) using a through-flow test which compares to 96-h LC_{50}s of between 13 and 20 ng/L for a static test (Cripe et al., 1989). Solomon et al (2001) used probabilistic modelling to estimate toxicity distributions and they reported values of 10ng/L for all organisms and 6.4 ng/L for anthropods as the 10th percentile. There are therefore a number of studies that indicate that cypermethrin can adversely impact on aquatic organisms at 50 ng/L, or even 10ng/L less.

The fact that the effect concentrations are at, or very close to the limits of detection may be a hindrance to accurately describing the environmental risk of cypermethrin. This may be more apparent for real environmental samples that contain organic matter that can cause interference in the analysis compared to laboratory-generated samples. There are also reports that organic carbon in real sediment can reduce the bioavailability of pesticides and reduce their toxicity compared to artificial sediments (Akerblom et al., 2008). Muir et al (1985) also demonstrated that the bioavailability of pyrethroids is lower in larvae associated with silt and clay sediments compared to sand sediments due to sorption. The work of Went-Rasch et al (2003) was conducted in a real lake thus it can be inferred that these NOECs and LC_{50}s account for sorption to sediment.

The work of Went-Rasch et al (2003) has shown that adverse effects can occur over a very short time period (4 hours) – durations that are relevant to sheep entering a stream. Based on the 6h-TWAC (Table 10) even if sheep had been left drying for two weeks (current guidelines) a small flock entering a small stream could contaminate it sufficiently (54 ng/L) to have an impact on *nauplii* (4-h LC_{50}: 50 ng/L). It should be noted that this is for a single, discrete time point and that the 6h-TWAC is likely to underestimate concentrations occurring over a 4-hour duration. If sheep entered on a daily basis for 28 days, the total numbers of sheep required to enter the stream over this period to give a 6h-TWAC of 50 ng/L are 51, 192 and 714 for a small, medium and large stream respectively (see below - 12.6.1 – for calculation).

A concentration of 10 ng/L, or less over a 5-day period could affect the olfactory functions of salmon (Moore & Waring, 2001). The 24h-TWAC data where sheep enter the stream on a daily basis (Table 14) are the most appropriate comparison to this environmental threshold. The numbers of sheep that need enter the stream to give a 24h-TWAC of 10 ng/L are 40, 152, and 556 in a small, medium and large stream respectively (see below - 12.6.1 – for calculation).

There have been relatively few studies on the toxicity of sediment-associated cypermethrin to benthic organisms. Muir et al (1985) demonstrated that bioconcentration factors (BCFs) for chironomid (midge) larvae in direct contact with sediment were generally twice that for larvae contained in water above the sediment for *cis*-cypermethrin; for *trans*-cypermethrin this was only true for the highest sediment concentration (640 ng/g). This study also reported that larvae were immobilised when cis-cypermethrin sediment concentrations were in the order of 174000 ng/kg wet weight, although many also survived when moved to clean water. All larvae survived 24 h of exposure to concentrations of

17000 ng/kg and 64000 ng/kg for *cis*- and *trans*-cypermethrin respectively. Maund et al (2002) reported much higher values for LC_{50}s for the same species with the 10-d median being 13, 67, and 62 mg/kg for sediments containing 1, 3, and 13% organic carbon; *Hyalella azteca* 10-d median LC_{50}s were 3.6, 18 and 32 mg/kg. The results of the TOXSWA modelling indicate that sediment-associated cypermethrin is unlikely to occur at concentrations that will aversely impact chironomid larvae or *Hyalella*.

The relatively high concentrations of cypermethrin in sediment potentially offer the opportunity for desorption over time, although in upland streams there is generally relatively little sediment. Muir et al. (1985) reported that 55% of *trans*-cypermethrin desorbed from sand into overlying water in 24 hours whereas this figure was only 4% for silt (silty-clay river sediment) and clay (pond bottom clay), indicating that quantities of cypermethrin in the water due to desorption are likely to be small compared to the initial inputs. There is also the possibility that this desorbed cypermethrin may re-sorb although there is no published literature to confirm this.

12.6.1 6h-TWAC calculations

There was a simple geometric relationship between all PECs, TWACs and the number of sheep. Using data from Table 13 it was possible to calculate the number of sheep required to give a TWAC of 50 ng/L for the different stream sizes:

Small: $50 \div 0.98 = 51$ Medium: $50 \div 0.26 = 192$ Large: $50 \div 0.07 = 714$.

The same process was used to calculate the number of sheep required to give a 24-h TWAC of 10 ng/L.

Small: $10 \div 0.25 = 40$ Medium: $10 \div 0.066 = 152$ Large: $10 \div 0.018 = 556$

12.6.2 References

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