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The influence of zinc sulphate solution on the fauna of chalk stream channels

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INTRODUCTION Zinc Sulphate is widely used by watercress farmers to control the incidence of the fungal disease "crook root". Crook root has an adverse effect on the production of watercress.

A solution of zinc sulphate is dripped or sprayed into the water flowing into watercress beds for a period of several months from autumn to spring. The objective of the application is usually to achieve a concentration of about 0.1 mg l^{-1} of zinc at the outflow from the watercress beds. There is usually a substantial dilution of the effluent concentration when it subsequently enters the receiving stream.

It has been suggested that zinc, a heavy metal which is toxic in high concentrations (Taylor et al. 1982), could be having an adverse effect on stream fauna, notably on the amphipod Gammarus pulex. The present study is a simple experiment designed to detect any gross short term effects of zinc sulphate solution on chalk stream invertebrates and invertebrate communities.

Materials and Labour (See appendix 1)

Methods

Chemistry

All sample bottles were soaked in 50% hydrochloric acid and then distilled-water washed three times to ensure that they were free of zinc contamination.

Analyses of all water samples and zinc solutions were made using a Varian 375 atomic absorption spectrophotometer.

A standard zinc solution of 1 g zinc per litre of River Frome water was made up with the addition of 10 ml of concentrated hydrochloric acid to ensure that all the zinc was in solution. This standard solution was then drip-fed at the necessary rate to produce the required concentration in each channel.

Table 1. Chemical analysis of River Frome inflow water

pH	7.92
Alkalinity m.e.l.	4.14
Calcium mg l^{-1}	90.6
Magnesium mg l^{-1}	2.34
Sodium mg l^{-1}	12.0
Potassium mg l^{-1}	2.2
Soluble reactive phosphate ug l^{-1} PO_4P	88.8
Nitrate mg l^{-1} NO_3N	5.10
Soluble silica as mg l^{-1} Si	3.45
Zinc ug l^{-1}	not detectable

Discharge

The discharge in each channel was measured and then regulated using valves situated at the upstream end of the channels. Flow calibration was compared using a standard fixed sluice board with an outflow pipe. The time was recorded for the flow from the pipe (after flow had stabilised) to fill a 16.6 l plastic bucket (mean time was c. 18 seconds $\equiv$ 0.92 l s^{-1}).

Channels

A diagram of the channel form (Fig. 1) and a picture of the layout (plates 1, 2 and 3) are given below. The treatments were allocated, at random, to the seven channels to give duplicate high, medium and low concentrations and a single, untreated, control.

Biological Methods

On 12 May 1987 at 1600 hrs, drift nets (1 mm mesh) (Fig. 1) were placed, at random, in four of the seven channels. Nets were removed at 0900 hrs on 13 May 1987. All animals were removed and preserved to provide an indication of natural (untreated) drift levels and variation.

On 13 May 1987 at 14.45 hrs drift nets were introduced to all channels to be removed at 0900 hrs on the following day.

On 13 May 1987 also at 14.45 hrs, cages (Fig. 2) containing refugia were placed in each channel. Unspecified numbers of *Gammarus pulex* were added to each upstream refuge. The *Gammarus* were collected from a tributary of the river Piddle at Waterston. The cages were removed on 18 May 1987 and the numbers of living and/or dead *Gammarus* in each refuge (compartment) was noted.

On 12 May 1987 at 1400 hrs 5 specimens of *G. pulex* (approx. 6 mm) were placed in duplicate plastic, 200 ml beakers containing 150 ml of zinc sulphate solutions of the following concentrations: 0.0, 0.05, 0.2 and 1.0 mg l^{-1}. The beakers were placed in an incubator at 14°C and examined twice a day for five days.

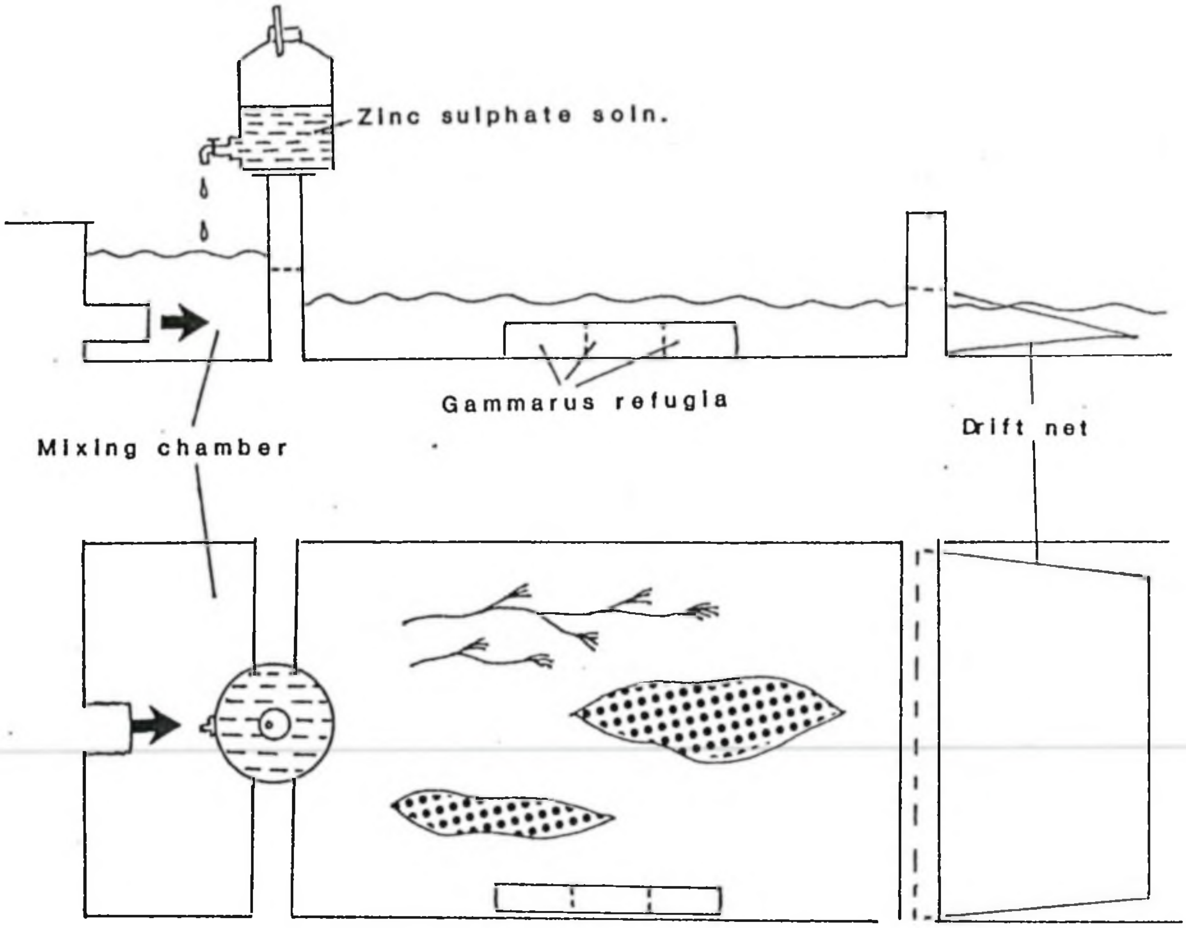

Figure 1. Diagram of the channels used in the present experiment

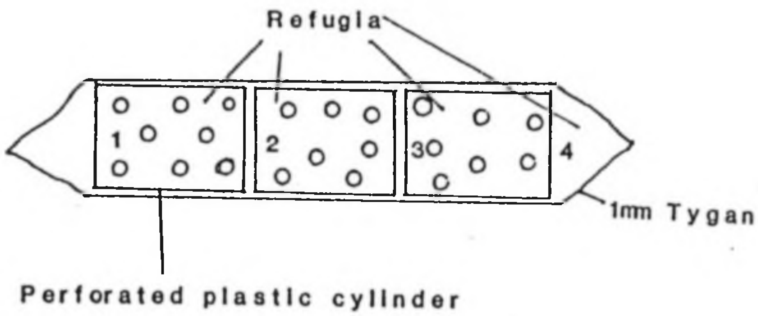

Figure 2. Refugia used to test the response of Gammarus to zinc addition

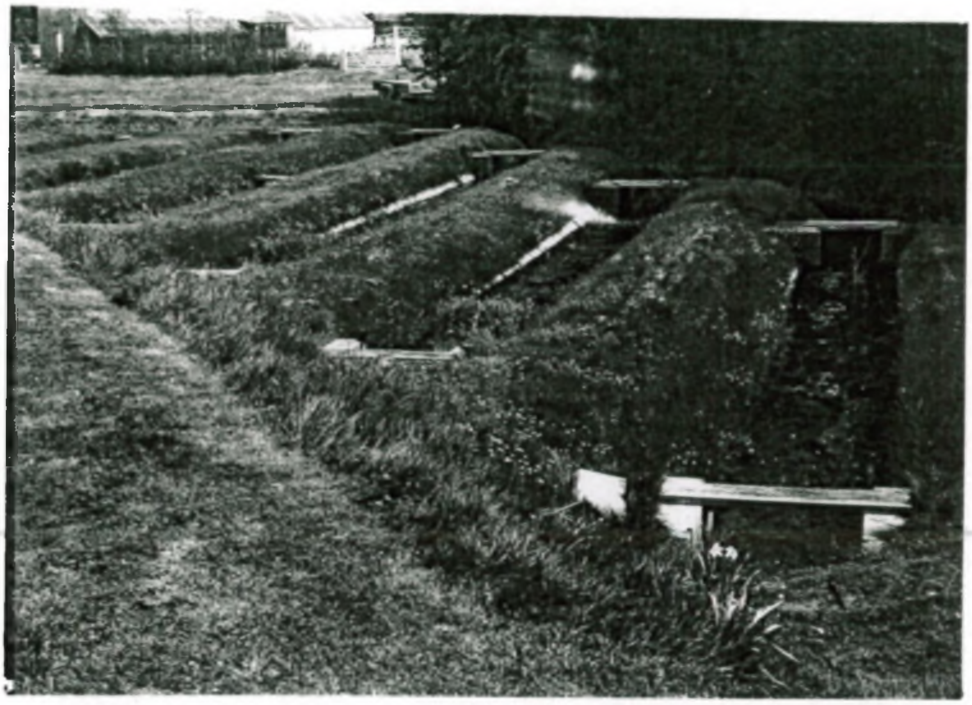

Plate 1. General view of the experimental channels

Plate 2. View of the channels showing the drip feeds in position

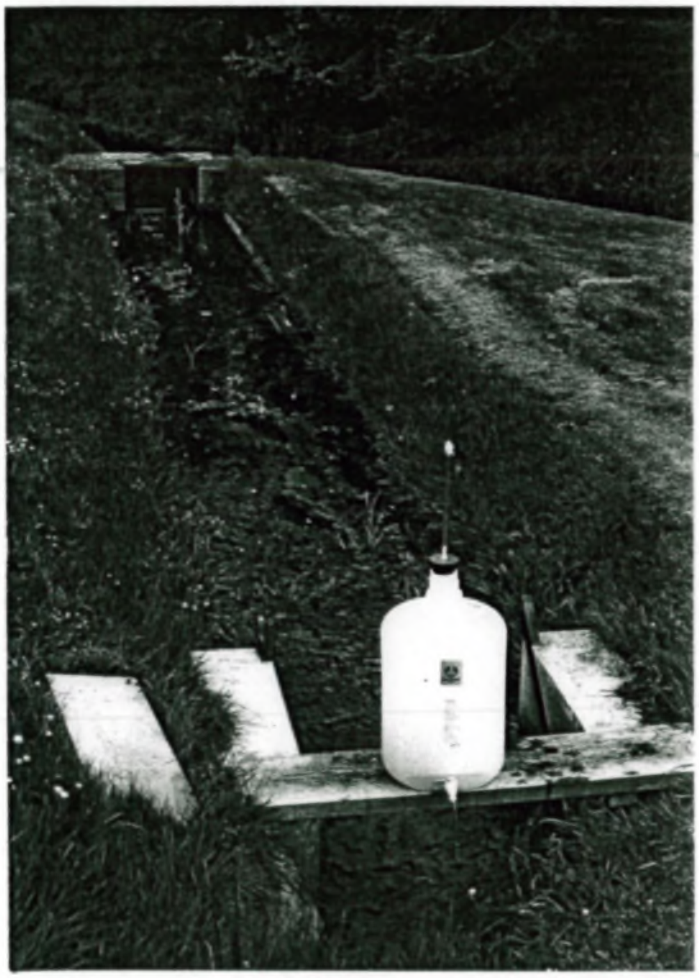

Plate 3. View of one channel with the drip feed in position

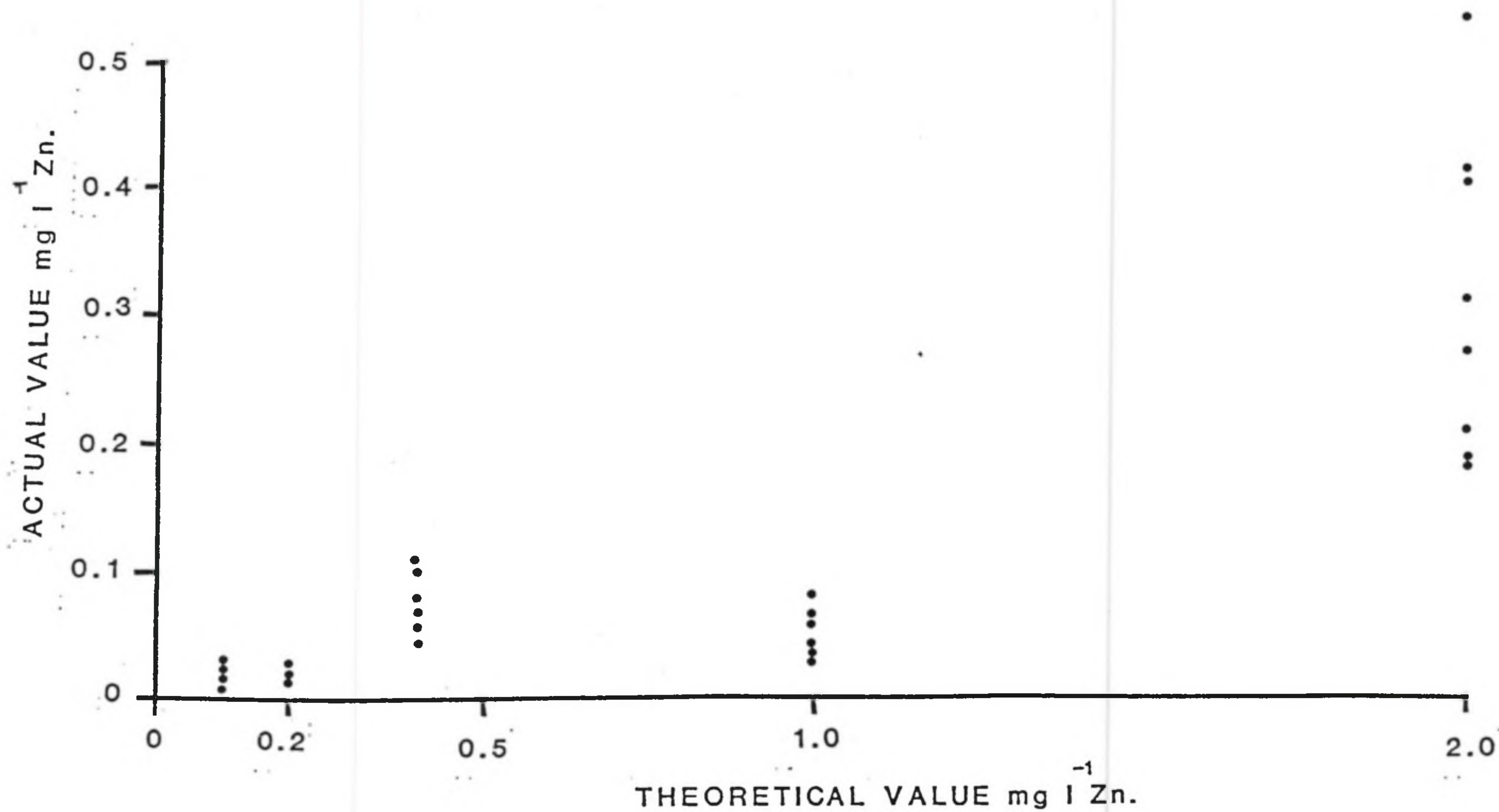

Figure 3. Graph of theoretical zinc value plotted against the zinc concentration in the outflow water of the channels

Table 2. Table to show the effect of controlled addition of Zinc Sulphate solution on the dissolved Zinc concentration in Chalk Stream channels

	Channel 5 - high addition			Channel 7 - high addition				
Time	mg l^{-1} Zn in outflow water	ml min^{-1} ZnSO sol^n added	Theoretical mg l^{-1} Zn in channel water	mg l^{-1} Zn in outflow water	ml min^{-1} ZnSO sol^n added	Theoretical mg l^{-1} Zn in channel water	Comparison of Zn mg l^{-1} in outflow of both high addition channels	
13.45	0.067	55.0	1.0	0.034	55.0	1.0	0.067	0.034
14.30	0.069	55.0	1.0	0.038	55.0	1.0	0.069	0.038
16.15	0.081	55.0	1.0	0.032	55.0	1.0	0.081	0.032
16.45	0.060	55.0	1.0	0.018	55.0	1.0	0.060	0.018
08.30	0.14	55.0	1.0	0.048	55.0	1.0	0.14	0.048
10.30	0.41	110.0	2.0	0.18	110.0	2.0	0.41	0.18
11.30	0.41	110.0	2.0	0.21	110.0	2.0	0.41	0.21
12.30	0.036	110.0	2.0	0.18	110.0	2.0	0.036	0.18
13.30	0.037	110.0	2.0	0.18	110.0	2.0	0.037	0.18
14.30	0.31	110.0	2.0	0.11	110.0	2.0	0.31	0.11
15.30	0.41	110.0	2.0	0.17	110.0	2.0	0.41	0.17
16.30	0.40	110.0	2.0	0.53	110.0	2.0	0.40	0.53
	Average mg l^{-1} Zn outflow = 0.20			Average mg l^{-1} Zn outflow = 0.14			Av = 0.20	Av = 0.14

Table 2 (continued)

Channel 3 - medium addition

Time	$mg\ l^{-1}$ Zn in outflow water	$ml\ min^{-1}$ ZnSO sol^{n} added	Theoretical $mg\ l^{-1}$ Zn in channel water
13.45	ND	11.0	0.2
14.30	0.005	11.0	0.2
16.15	0.014	11.0	0.2
16.45	0.004	11.0	0.2
08.30	ND	11.0	0.2
10.30	0.019	22.0	0.4
11.30	0.045	22.0	0.4
12.30	0.045	22.0	0.4
13.30	0.077	22.0	0.4
14.30	0.066	22.0	0.4
15.30	0.037	22.0	0.4
16.30	0.032	22.0	0.4

Average $mg\ l^{-1}$ Zn outflow = 0.034

Channel 6 - medium addition

$mg\ l^{-1}$ Zn in outflow water	$ml\ min^{-1}$ $ZnSO$ sol^{n} added	Theoretical $mg\ l^{-1}$ Zn in channel water	Comparison of Zn $mg\ l^{-1}$ in outflow of both medium addition channels	
0.007	11.0	0.2	ND	0.007
0.016	11.0	0.2	0.005	0.016
0.026	11.0	0.2	0.004	0.010
0.010	11.0	0.2	0.004	0.010
0.019	11.0	0.2	ND	0.019
0.071	22.0	0.4	0.019	0.071
0.10	22.0	0.4	0.045	0.10
0.076	22.0	0.4	0.045	0.076
0.11	22.0	0.4	0.077	0.11
0.060	22.0	0.4	0.066	0.060
0.048	22.0	0.4	0.037	0.048
0.045	22.0	0.4	0.032	0.045

Average $mg\ l^{-1}$ Zn outflow = 0.049 | Av = 0.034 | Av = 0.049

Table 2 (continued)

Channel 2 - low addition

Time	mg l^{-1} Zn in outflow water	ml min^{-1} $ZnSO$ sol^{n} added	Theoretical mg l^{-1} Zn in channel water
13.45	ND	2.7	0.05
14.30	0.007	2.7	0.05
16.15	0.026	2.7	0.05
16.45	0.004	2.7	0.05
08.30	ND	2.7	0.05
10.30	ND	5.5	0.1
11.30	0.042	5.5	0.1
12.30	0.036	5.5	0.1
13.30	0.065	5.5	0.1
14.30	0.035	5.5	0.1
15.30	0.030	5.5	0.1
16.30	0.027	5.5	0.1

Average mg l^{-1} Zn outflow = 0.027

Channel 4 - low addition

$mg\ l^{-1}$ Zn in outflow water	$ml\ min^{-1}$ $ZnSO$ sol^n added	Theoretical $mg\ l^{-1}$ Zn in channel water	Comparison of Zn $mg\ l^{-1}$ in outflow of both low addition channels	
ND	2.7	0.05	ND	ND
0.007	2.7	0.05	0.007	0.007
0.035	2.7	0.05	0.026	0.035
0.004	2.7	0.05	0.004	0.004
0.014	2.7	0.05	ND	0.014
ND	5.5	0.1	ND	ND
0.009	5.5	0.1	0.092	0.009
0.008	5.5	0.1	0.036	0.008
0.039	5.5	0.1	0.065	0.039
0.015	5.5	0.1	0.035	0.015
0.0085	5.5	0.1	0.030	0.008
0.0050	5.5	0.1	0.027	0.005

Average $mg\ l^{-1}$ Zn outflow = 0.014   Av = 0.027   Av = 0.014

Table 2 (continued)

Channel 1 - Control

Time	$mg\ l^{-1}$ Zn in outflow water	$ml\ min^{-1}$ ZnSO sol^{n} added	Theoretical $mg\ l^{-1}$ Zn in channel water
13.45	ND	-	-
14.30	0.009	-	-
16.15	0.014	-	-
16.45	0.004	-	-
08.30	ND	-	-
10.30	ND	-	-
11.30	ND	-	-
12.30	ND	-	-
13.30	0.005	-	-
14.30	ND	-	-
15.30	0.006	-	-
16.30	ND	-	-

Average $mg\ l^{-1}$ Zn outflow = 0.0076

Results

Chemical

Table (1) shows the chemical composition of the River Frome water feeding the experimental channels. Table (2) shows the concentrations of zinc attained by controlled additions of zinc sulphate to the seven channels. The zinc concentrations measured at the outflow points of the channels were always less than the theoretical values calculated on the basis of discharge and zinc additions. Duplicate treatments differed widely in the concentrations attained. Because of the low concentrations observed, the application rate of zinc sulphate solution was doubled in all cases. As a result of this the concentration of zinc in the outflows was usually more than doubled but was still very variable and was considerably less (c. 10-20% of the theoretical value) (maximum values 0.41 mg l^{-1} in channel 5 and 0.53 mg l^{-1} in channel 7 - theoretical value 2.0 mg l^{-1} in both cases).

Although some variation in discharge during the experiment may have occurred it could not account for these large variations or decreases in zinc concentration. It was concluded that zinc was being lost from solution at varying rates within the experimental channels by process of uptake, adsorption and absorption onto sediments, flora and fauna. This was borne out by the relationship between theoretical concentration and measured concentration (Fig. 3). In addition, a controlled laboratory experiment at pH 8.3 at 25°C indicated that there was rapid uptake of zinc from solution by natural stream sediments (approx. 1 mg zinc/g sediment after 10 minutes). This rate will, of course, depend on the nature of the sediment and on other environmental factors.

Biological

Drift

Table (3) indicates the nature of the main drift found in all seven channels (1) prior to treatment and (2-3) during treatment with zinc solutions.

Table 3

Channel No.	1 Control	2 low	3 med	4 low	5 high	6 med	7 high
13 & 14 May 1. 1445-0900	S,B,E,T (3)	few (1)	T,E,Ep (2)	B,E,T (3)	E,Ep (2)	S,B,E (3)	few (1)
14 May 2. 0900-1500	S,B,E,T (3)	few (1)	T (2)	T (3)	G (1)	S,B,T,Ch (3)	few (1)
14 & 15 May 3. 1500-0900	S,B,E,T (3)	few (1)	T,E,Ep (2)	T,Ep,C (3)	few (2)	S,B,E,Ch (3)	few (1)

S - Simuliidae B - Baetidae E - Elminthidae
T - Trichoptera Ep - Ephemeridae C - Coleoptera
G - Gammarus pulex Ch - Chironomidae

(1) <10 (2) 10-100 (3) >100 no. of animals

Both the level of drift and the nature of the drifting animals appears to be characteristic of the channel and to vary little, if at all, with the concentrations of zinc achieved in the present study.

Gammarus refugia

The percentage of live and dead Gammarus pulex in the various compartments (refugia) of the cages in each treatment are indicated in Table (4).

Table 4

Percentage of Gammarus pulex in each refuge at conclusion of experiment

Channel No.	Control 1		Low 2		Med 3		Low 4		High 5		Med 6		High 7	
	D	L	D	L	D	L	D	L	D	L	D	L	D	L
Refuge No.														
1 (introduced)	(50)	-	-	54	-	48	-	9	(28)	44	-	60	(28)	44
2	-	50	-	-	-	9	-	16	-	14	-	-	-	-
3	-	-	-	18	-	5	-	-	-	14	-	40	-	-
4	-	-	-	28	-	38	-	75	-	-	-	-	(14)	14

D = dead L = live

No clear pattern emerges for, although dead Gammarus were present in the upstream refugia of both high concentration channels (5 and 7), they were also present in the upstream refuge of the control channel (1). In all cases except channels 1 (Control) and 4 (Low), a high proportion of the Gammarus had remained in the upstream refuge in which they were originally placed.

There is no evidence of either mortality due to zinc additions or of downstream shift (behavioural response) following zinc additions.

Gammarus in culture solutions

No deaths and no obvious distress of Gammarus was observed over the first two days. After three days all Gammarus in the solution containing 1.0 mg l^{-1} of zinc were dead. No deaths occurred after five days in any other concentration. In view of these observations it is unlikely that direct zinc toxicity was responsible for mortality of Gammarus in the refugia (above).

In conclusion:

No short-term effects of zinc additions on chalk stream invertebrates were detected.

A large proportion of added zinc was quickly lost from solution.

Laboratory experiments showed that zinc uptake onto chalk stream sediment is rapid.

No changes in level or nature of invertebrate drift were observed.

Gammarus pulex, although killed within two days by a high zinc concentration (1.0 mg l^{-1}) were apparently unaffected at the concentrations theoretically achieved downstream of watercress beds.

Summary and recommendations

The main aim of the present experiments was to determine whether there is a direct effect of zinc sulphate concentrations of 0.05, 0.20 and 1.00 mg l^{-1} zinc on the fauna of experimental through flow channels.

The drift of the fauna was monitored over a period of 72 hours (24 hours prior to treatment, 48 hours during treatment).

The response of caged *Gammarus pulex* to the above concentrations of zinc was noted.

Gammarus were maintained in an incubator at 14^{o}C in the above concentrations of zinc sulphate and observed daily to determine resultant mortality.

Although these simple experiments are in no way conclusive it would appear that direct short term toxicity of zinc is unlikely to be responsible for faunal changes observed in streams fed by watercress farms.

However, observations from a small chalk stream on 27.5.87 gave the following results:

Site 1 (upstream of watercress beds)

Large numbers of Gammarus pulex present in net samples (3 minutes)

Site 2 (downstream of small watercress farm)

Few Gammarus pulex present

Site 3 (immediately downstream of a second, larger, watercress farm)

One or two Gammarus pulex present

Sites 4 & 5 (2-3 Km downstream of site 3)

No Gammarus pulex present at either site

In the late 1960's the latter sites contained abundant Gammarus (Ladle pers. comm.) and this organism was often 10-25% of gut contents of trout (Mann & Orr 1969).

It would appear that long term changes in the populations of Gammarus pulex (at least?) have taken, or are taking place on some chalk stream sites. If the reasons for such changes are to be determined it will require a much more detailed and expensive research programme involving:

A. Longitudinal, chemical and biological surveys of selected chalk streams over a twelve month period.

B. Studies on toxic effects of zinc solutions at various stages in the life history of Gammarus pulex.

C. Investigation of the effects of zinc on fecundity, growth, mortality and behaviour of Gammarus pulex.

D. Studies on the effect of zinc associated with sediment or plant material when used as a food source for aquatic invertebrates.

In the present study only the effects of zinc have been considered. However, because of the complexity of chalk stream ecosystems and the interactions between water, sediments and biota it is possible that other factors (e.g. pesticides, changes in management) could be responsible for the observed changes in Gammarus populations. The causes should if possible be established and a solution found as soon as possible to avoid irreversible damage to the ecosystem.

References

Mann R.H.K. & Orr D.R. (1969). A preliminary study of the Feeding Relationships of fish in a hard-water and a soft-water stream in Southern England. J. Fish Biol. 1. 31-44.

Taylor M.C., Demaye A., & Taylor K.W. (1982). Effects of zinc on humans, laboratory and farm animals, terrestrial plants and freshwater aquatic life. C.R.C. Critical Reviews. Environmental Control, 12, 113-181.

APPENDIX 1

Materials and labour used

Materials

7 throughflow channels fed by River Frome water

Zinc Sulphate solutions

Dripfeeds and mixing chambers

Drift nets

Cages for enclosing *Gammarus pulex*

Labour

Water analysis using atomic absorption spectrophotometry

Setting up of zinc drip apparatus

Setting up of drift nets and *Gammarus* cages

Collection of *Gammarus pulex*

Counting and identification of invertebrates

Analysis and writing up