6

Small animals in drinking-water distribution systems

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6.1 INTRODUCTION

Invertebrate animals are naturally present in many water resources used as sources for the supply of drinking-water. Small numbers of adults or their larvae may pass through water-treatment works if the barriers to particulate matter are not completely effective. Their motility may also enable them to penetrate filters at the treatment works and vents on storage reservoirs.

Many of these animals can survive (and some may even reproduce) within the supply network by deriving their food from the microorganisms and organic matter in the water or (more commonly) present in deposits on pipe and tank surfaces. Populations of small animals are surprisingly widespread in treated-water distribution systems. Reports from most continents suggest that few, if any, water distribution systems are completely free of animals. However, the density and composition of animal populations vary widely, from heavy

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infestations of readily visible species that are objectionable to consumers, to sparse occurrences of microscopic species. In spite of their ubiquity, these animal populations have not been widely studied and their biology is not well understood.

In temperate countries, no population of pathogenic animals has been found, or would be expected to be found, in a distribution system. The presence of animals has largely been regarded by water suppliers as an 'aesthetic' problem, either directly or through their association with discoloured water. However, there have been suggestions that their presence may affect the microbiological quality of water.

In tropical and subtropical countries, certain species of aquatic animal can act as secondary hosts for parasites. For example, the small crustacean *Cyclops* is the intermediate host of *Dracunculus medinensis*, the guinea worm — the only parasite that is known to be transmitted solely by water consumption (WHO, 1996). However there is no evidence that guinea worm transmission occurs from treated-water piped supplies.

In all countries, the presence of living animals or animal debris will reduce the acceptability of a water supply. People may then change to alternative supplies that may be less safe. Thus, for reasons of public health, it is important to prevent the entry and proliferation of animals in water distribution networks.

This chapter discusses:

- the occurrence and significance of metazoan (many-celled) animals in treated drinking-water distribution systems;
- the limited information available on their relationship with the microbiological quality of water and health concerns;
- methods of controlling populations of animals in the supply network.

This chapter does not deal with animals infesting raw water pipelines.

6.2 OCCURRENCE OF ANIMALS IN DISTRIBUTION SYSTEMS

6.2.1 Extent

There are reports in the literature of animals in water distribution systems from North America, Europe, Africa, South Asia and East Asia, from the late 19th century (before the widespread introduction of filtration and disinfection) into the 21st century. For example, the animal populations of water distribution systems were studied in the United Kingdom in the 1960s and 1970s; about 50 systems were sampled, and animals were found in all of them, although the water suppliers and their consumers were often unaware of their presence. About 150 species of animal were identified (Smalls & Greaves, 1968), including a species that had not been recorded from natural waters since the 1920s, but had been found in several water distribution systems. A systematic survey in the 1990s of water distribution systems supplied by 36 treatment works in the Netherlands also found animals in all of them, although fewer taxa were identified (van Lieverloo, 1997). Water pipes evidently provide a favourable environment for a variety of small aquatic animals.

No systematic studies have followed the numbers of animals present in distribution systems over a long period. Ad hoc observations from water suppliers suggest that, where the efficacy of water treatment has improved, animal numbers have probably declined.

6.2.2 Sampling

The usual method of sampling animals in water pipes is to flush a standard volume of water from a hydrant at a controlled flow rate, and to capture particulate matter, including animals, in a fine-meshed sampling net. The catch is sorted in a trough with a through flow of water, the species identified and their number estimated. Results are often only semiquantitative, the number of individuals of a particular species in a sample being expressed as an order of magnitude (1–9, 10–99, 100–999 etc.) (Smalls & Greaves, 1968).

More elaborate methods have been proposed. Van Lieverloo (1997) used a device that split the flow from the hydrant, part being filtered through a 500 μm mesh, and part being passed through an additional 100 μm mesh. Smart (1989) used repeated flushing of the same hydrant, and extrapolated from the declining numbers found in successive samples from the same point to estimate the total population in the length of main being sampled. Because different species show a different propensity to be flushed from the pipe, it was necessary to make a separate extrapolation for each. However, such methods have not found widespread favour, partly because it is uncertain how representative samples are, and partly because the considerable effort involved in making the sampling and counting more quantitative is usually not thought to be worthwhile for making short-term operational decisions. Consequently, few data exist on the biomass of the various species or on the dynamics of the ecosystems in water mains.

Plate 6.1. Sampling animals and loose deposits in a fine-meshed sampling net.

6.2.3 Ingress

Animals may be present in water distribution systems because:

- they enter the distribution system with the incoming water, having passed through treatment processes or having colonised parts of the treatment plant;
- they enter through defects in the integrity of the distribution system, such as badly screened service reservoirs;
- they form breeding populations within the distribution systems.

Animals that are aquatic for the whole or part of their life-cycle may gain initial entry to the system by penetration through treatment works. The animals that successfully penetrate treatment processes are largely benthic species (Evins & Greaves, 1979) — that is, species that live on the bottoms or margins of water bodies. Where water from upland reservoirs of good microbiological quality with a low content of suspended solids receives only limited treatment, planktonic species may enter the distribution system in appreciable numbers. However, they do not usually thrive there. Some benthic species have also been found to colonise filter beds and other parts of treatment works, and this has been shown to influence the numbers and species in the treated water leaving the works. The relative importance of this mechanism is unclear, but the species found in each situation suggest that it in most cases it is probably less important than the direct passage of animals with the water being treated.

Service reservoirs may be a point of entry for species that are aerial for part of their life-cycle. For example, flying insects may enter through badly protected vents and overflows, and lay eggs at the water surface, which develop into aquatic larvae. Significant ingress of chironomid (gnat) larvae may take place in this way. Terrestrial species may enter as a result of inadequate care in laying mains or through cracks and poorly fitting access covers at service reservoirs; the resulting problems are transient and cease when the access point is blocked.

The ingress of small numbers of aquatic animals through treatment works and the establishment of breeding populations in the distribution system is responsible for by far the greatest number of individuals. The initial entry of a species may have been some time ago, when water treatment was less effective than it is now, or it may be the result of periodic treatment failures.

Although a large proportion of the species that penetrate treatment works are benthic, and all those that thrive in the mains are benthic, it is not necessarily the species that pass treatment in the greatest numbers that are most common in the mains. A survey (Evins & Greaves, 1979) of treatment works and their associated distribution systems showed that, for most species, it is success of reproduction within the main that determines the size of the population. Thus, the species that are common in the distribution system are not necessarily those that appear most frequently at consumers' taps (van Lieverloo, 1997). This is because the species that thrive in the pipework may resist dislodgement and suspension in the conveyed water, whereas those that are present in the incoming supply may pass directly to consumers' taps.

Only animals that are aquatic for the whole of their life-cycle can colonise the distribution system and form breeding populations there. This excludes most insect larvae. Nevertheless, larvae of many species of chironomid may be present in the distribution system in appreciable numbers. Larvae are often present in large numbers in rivers and reservoirs, and may penetrate treatment works. These insects may colonise filter beds, they may also lay eggs in open tanks in treatment works or in badly protected service reservoirs.

However, several species of chironomid are parthenogenetic (females are able to reproduce without males), and have eggs that begin to develop within the pupa. In at least one species, *Paratanytarsus grimmii*, and possibly others, if emergence of the (normally aerial) imago is prevented (e.g. by lack of access to air) viable eggs are released from the pupa. Thus, successful reproduction is possible within the confines of water mains, and these insects have been particularly troublesome in water distribution systems in Europe and North America. (Krüger, 1941; Williams, 1974; Berg, 1995).

6.2.4 Population size

For some species, numbers depend on ingress from outside the distribution system; however, for most species, there are breeding populations within the distribution system that interact to form an ecosystem. The size of these populations depends on intrinsic characteristics, such as their adaptability to conditions in a water pipe, their reproductive potential and external factors, such as temperature and (most importantly) food supply. The majority of the species that thrive in water mains feed in their natural habitats on particulate organic matter or plant material. For example, the chydorids, which are often the most numerous group, feed by filtering small particles from water close to solid surfaces. One of the most successful of the larger colonizers of water mains, *Asellus aquaticus*, is a detritivore (an organism that feeds on nonliving organic matter) and is a fairly indiscriminate feeder. The faeces of *Asellus* taken from iron water mains contain about 70% by weight of iron oxides (Water Research Association, United Kingdom, unpublished data). Other species may graze more directly on surface biofilms.

Populations of these detritivores and grazers can flourish in the relative absence of pressure from carnivores. A number of small carnivorous species have been found, such as *Cyclops albidus*, which would feed on the smaller chydorids. However, larger carnivores are rare or absent. Fish are usually the 'top carnivores' in freshwater ecosystems, consuming invertebrates such as insect larvae, and are effectively absent from treated water distribution systems.

Thus, one may imagine that the food-chain in the water mains ecosystem is a relatively short one: most of the animal species present are at the same trophic level. They would be either competing directly for the same food supply of organic detritus and microorganisms, or using separate parts of it, divided for example by size and by whether or not they are attached to the substrate. Smart (1989) has studied the diversity of animals recolonising pipework following flushing. He found little pattern to the recolonisation in apparently similar situations, and concluded that there was a 'competitive lottery': the species which by chance arrived first being able to establish substantial populations.

Various observations and studies have shown a link between the type of water source, particularly its organic content, and the extent of animal populations in the water mains. Water from deep underground sources generally supports lower numbers of animals than water from surface sources, probably because water from underground has a low organic content. Increases in animals in the mains have been attributed to penetration of algae and to the introduction of treatment processes that are less effective at reducing the organic content of the water. Variations in the organic content of the water at one works have been linked to changes in the numbers of some groups of animals (Evins & Greaves, 1979), although these were unsophisticated studies. No known studies have quantified the interactions between the major elements of the system, namely the organic material entering the distribution system, the heterotrophic microorganisms in the pipework and the animals in the pipework.

It would be reasonable to suppose that the type of organic material is significant. Some particulate organic matter, such as algal cells and other plant material, may directly contribute to the food supply for filter feeders and detritivores. Increases in populations of *Asellus aquaticus* have been noted after high algal numbers in raw water, the introduction of water from surface sources and a change to treatment processes that were less effective at removing algae. Biodegradable dissolved organic material contributes to microbial growth (see Chapter 2) and thus to the food supply for animals, although the more refractory dissolved or colloidal organic material, such as the humic material prevalent in some upland waters, is likely to be less suitable.

As a generalization, the trophic interactions may be summarized as in Figure 6.1. The relationships involved have not been satisfactorily quantified. In particular, there is lack of information on the quantity of biofilm material necessary to support populations of grazing animals, and a corresponding lack of information on the effect of the grazing on the quantity and species composition of biofilms.

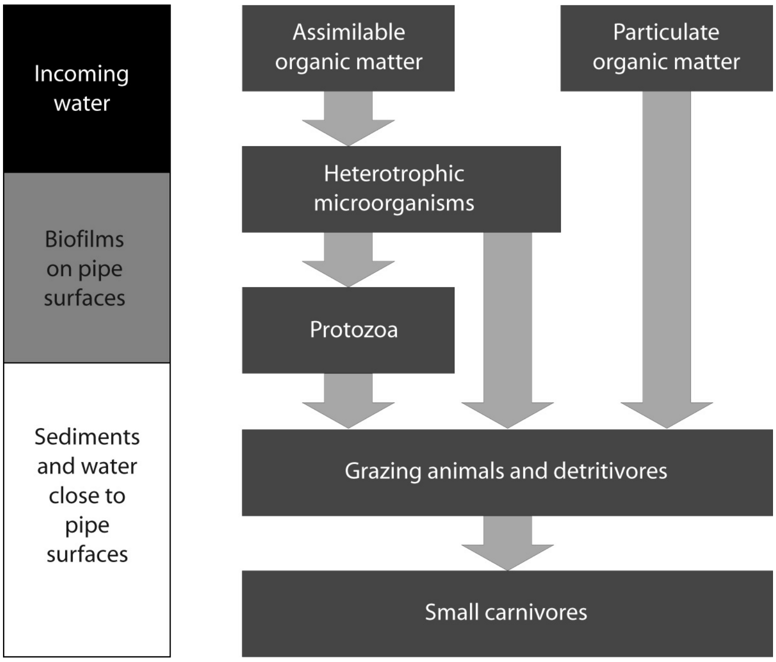

Figure 6.1. Generalized trophic interactions in water distribution systems.

Recommendations have been made to limit the potential for the growth of animal populations in water mains by limiting the amount of organic matter entering the distribution system (Evins, Liebeschuetz & Williams, 1990; van Lieverloo, 1997). The severity of infestations has declined in some countries in recent years; this may be related to improvements in the efficacy of water treatment not primarily introduced for this reason.

6.3 SIGNIFICANCE OF METAZOAN ANIMALS IN DRINKING-WATER DISTRIBUTION SYSTEMS

6.3.1 Aesthetic problems

The presence of animals has largely been regarded by water suppliers in temperate countries as an "aesthetic" problem. The few studies in distribution systems and the animal control activity by water suppliers have been concerned with the aesthetic aspects. The larger animals may be visible to the consumer and may be objectionable if they appear at the tap. Also, animals are associated with discoloured water problems as both cause and effect; the animals thrive at points of low flow, such as dead end mains and badly encrusted pipes, where sediments accumulate. Examination of samples of discoloured water has sometimes revealed that the particulate matter consists largely of fragments of animals, such as the cast carapaces of chydorids, which are stained with iron.

The decay of animals and their faeces may create the potential for taste and odour problems. Alternatively, the animals may have a beneficial effect — by feeding on particulate organic matter they limit the potential growth of microorganisms such as actinomycetes, which can cause taste and odour problems. Both these hypotheses are conjectural. In view of the much greater biomass of microorganisms than that of animals, and the known association between some of these microorganisms and odour problems, the beneficial effect seems more likely.

6.3.2 Metazoan parasites

In temperate countries, there is no evidence that any of the metazoan animals found in water distribution systems are directly harmful to human beings.

In tropical and subtropical countries, certain species of aquatic invertebrate animal act as intermediate hosts for parasites. The parasitic nematode *Dracunculus medinensis*, the guinea worm, presently occurs in sub-Saharan Africa only, but regions where it has been historically endemic also include North Africa, Middle East and the Indian subcontinent. It is transmitted solely by water consumption (WHO, 1996). *Cyclops* is its intermediate host: one larval stage develops within the crustacean, and human infection (dracunculiasis) results from ingesting water containing infected *Cyclops*. Further larval development and growth of the adult worm (up to 1 m in length) takes place in subcutaneous tissue. Juvenile worms are released: these cause a severe allergic reaction and ulceration, which often becomes infected by bacteria. The sufferer often uses water to cool the inflamed and infected areas, allowing the juvenile worms to return to water and infect new *Cyclops*. Thus, in areas where dracunculiasis is prevalent, raw water should be treated sufficiently well to remove *Cyclops*. However, there is no evidence that guinea worm transmission occurs from piped drinking-water supplies.

The five species of the parasitic flatworm *Schistosoma* that cause schistosomiasis (bilharziasis) have occurred in many countries in Central and South America, Africa, Asia Minor, South-East Asia and the Western Pacific (WHO, 1996). They have a complex aquatic life-cycle with aquatic snails as their intermediate hosts. Eggs released by human beings develop into miracidia, which are infective to snails, where they develop and release sporocysts. These in turn develop into cercariae, which are infective to human beings. Thus, in the tropical and subtropical regions where schistosomiasis is prevalent, the presence of snails in the distribution system could pose a hazard. If the snails are not already infected, it is possible they will become so if eggs or miracidia pass through treatment. Again, this is a theoretical risk and there is no evidence of piped distribution systems acting as a transmission route for this disease.

6.3.3 Effect of animals on occurrence of microorganisms in water mains

There have been suggestions that the presence of animals may have an effect on the microbial quality of water. Animals play a role in the biological equilibrium in the distribution system. The animals present in water mains occur predominantly in sediments or close to the pipe walls, and this is where microorganisms are concentrated. Most of the animals present in water mains are filter feeders or detritivores, and it could be expected that the microorganisms form a substantial proportion of the material ingested by the animals. Although a microbial flora may be present in the gut of the animals, it is likely that the predominant effect of the animals will be to exert a "grazing pressure" by ingesting and inactivating microorganisms. This may reduce the biomass of microbial material present, and may have a selective effect on the relative abundance of microbial species present. However, no studies have quantified either of these effects.

It has been noted that when control measures are applied against some species of animal in water distribution systems, the composition of the pipe fauna changes and other species increase. It is not known what effect such changes have on the composition of the biofilms.

6.3.4 Association between animals and pathogens

In natural waters, bacteria are present in the gut of various invertebrates and on their surfaces. This has led to speculation that, if the same were true of invertebrates in water supplies, this may be of sanitary significance. The microorganisms present in the guts of the invertebrates are likely to reflect those in the sediments and biofilms where they are feeding. In distribution systems carrying treated water, these would not normally be expected to include significant numbers of pathogens, and there is no reason to suppose that pathogens would be selectively favoured.

Viruses and parasites require specific hosts, and pathogenic bacteria generally require higher temperatures for multiplication than those found in water mains, at least in temperate countries. In the tropics, the situation may be different. Temperatures may be high enough to allow the proliferation of organisms such as Legionella, which multiplies above about 20°C. Legionella, which is infective through inhalation, has been isolated from protozoa (Lee & West, 1991); the possibility that it may also survive in macroinvertebrates cannot be discounted.

Among the few studies of the microflora associated with animals from water supplies, Levy, Hart and Cheetham (1986) took amphipods, insect larvae and copepods from samples from a distribution system in the USA. These animals were homogenised and the microflora studied. No enteric pathogens or coliforms were isolated in spite of the presence of coliforms in a service reservoir in the system. Some species which may be regarded as "opportunist" pathogens were identified: *Aeromonas*, *Pseudomonas*, *Serratia* and *Staphylococcus*. However, there is no evidence of any association of these organisms with waterborne gastrointestinal infection for the population at large (WHO 2003). Lupi, Ricci and Burrini (1995) examined the microflora of the guts of nematodes taken from a treated water supply and from the raw water from which it was derived. They found Enterobacteriaceae in the nematodes from both situations, although these bacteria were of nonpathogenic genera. Far fewer bacteria were found in the nematodes from the treated water.

6.3.5 Protection from disinfection

A few studies have suggested that invertebrates could harbour microorganisms in their gut and protect them from disinfection. Chang et al. (1960) conducted laboratory experiments using two species of nematode isolated from potable water in the USA and exposed to suspensions of microorganisms. They demonstrated that the nematodes would ingest *Salmonella* and *Shigella* bacteria, and coxsackie and echo viruses. A small proportion (around 1%) of these microorganisms survived in the gut of the nematodes for 48 hours. The nematodes were shown to be highly resistant to chlorination, and viable microorganisms were isolated from the gut after the nematodes were subject to chlorination. Chang et al. (1960) did not demonstrate the excretion of viable pathogens, but Smerda, Jensen and Anderson (1971) showed that viable *Salmonella* might be excreted by a nematode.

Levy et al. (1984) exposed amphipods to suspensions of *Escherichia coli* and *Enterobacter cloacae*, subjected them to chlorination (1 mg/l for 60 minutes), homogenized the animals and determined the count of viable bacteria. Viability of the bacteria in or on the amphipods was reduced to about 2% (*E. coli*) and 15% (*Enterobacter cloacae*). In contrast, bacteria that had not been in the presence of the amphipods were reduced to about 1% in 1 minute at this concentration of chlorine.

These studies demonstrated the possibility that invertebrates may protect microorganisms from disinfection, although they did not quantify the risks involved. It has not been demonstrated that pathogens have actually been present in a distribution system as a result of such a mechanism.

Theoretically, this mechanism could occur in the distribution system, although it would present a significant risk only if pathogens were already present in the distribution system and were protected from the levels of disinfectant carried through distribution. The microorganisms most likely to be protected in this way are those present in biofilms and sediments, which themselves offer protection from disinfection. It could be argued that grazing animals allow more effective penetration of disinfectant, by reducing the amount of organic matter present in biofilms and sediments. However, this theoretical possibility should not detract from the general objective of minimizing the formation of deposits and biofilms in the distribution system by appropriate treatment (Chapter 2) and routine maintenance (Chapter 4).

Another possibility raised by these studies is that some invertebrates could harbour microorganisms in water-treatment works, protect them from disinfection and carry them through treatment into the distribution system. This hazard only applies to the small numbers of animals passing treatment and not to the populations breeding in the distribution system. It represents a possible mechanism by which pathogens may be transported from a situation in which they may be relatively abundant (i.e. polluted raw water) to one in which otherwise they would be absent or rare (i.e. the treated water). Thus, the animals that warrant closer attention are likely to be those that appear to pass treatment more readily, such as chironomid larvae and nematodes. Again this risk is purely hypothetical and has not been observed in a piped-water supply system.

6.4 REMEDIAL MEASURES

6.4.1 Range of methods

The methods available for controlling existing infestations of animals in water mains include physical methods (essentially the mains cleaning techniques referred to in Chapter 4) and some chemical methods. The physical methods have the advantage of removing the sediments that provide habitat and food supply for animals, as well as the animals themselves. Effective application of the chemical methods also involves flushing. The most important of the chemical agents are pyrethroids, which are effective against a range of arthropods, including chironomid larvae and *Asellus*. Any chemical agent should be specifically approved for use in drinking-water (see WHO, 2004) Long-term control measures are recommended to restrict the potential for the growth of animal populations.

Regular monitoring of populations of animals in the distribution system, using the methods outlined in Section 6.2.2, will provide information on their relative abundance in different parts of the system and on changes in their numbers. This allows control measures to be taken pre-emptively in a planned manner at a time chosen by the water supplier, before numbers become high enough to cause major problems.

The choice of method adopted to control a particular infestation will depend on the species of animal present, whether consumers will tolerate them, their ease of removal and the numbers present. In general, species that move freely in the water or on the surface of the pipe or deposits (e.g. *Cyclops*) are relatively easily removed by flushing; whereas, those that burrow in deposits (e.g. nematodes, chironomid larvae) require action that is more stringent. Species that cling to the pipe surface (e.g. *Asellus*, aquatic gastropod snails) require dislodging before they can be flushed from the main.

Most of the methods involve the use of flowing water; they should be applied working systematically ‘downstream’, starting at the treatment works if practicable. No main that has been treated or is being treated should receive water from an untreated main. This is important to reduce recolonisation of cleaned mains; it requires accurate mains records and invariably involves several valving operations. For the methods to be effective, and to avoid unwanted side-effects, it is important that work is planned carefully and carried out thoroughly (see Section 4.4).

6.4.2 Physical methods

Systematic unidirectional flushing

Systematic flushing (see Section 4.4.2) removes most freely swimming animals, provided that adequate flows are available. In smooth pipes, it will also remove loose deposits and animals burrowing within them, but higher flows are required to achieve good results. Although most animals are of relatively low density, the pipe deposits often have a specific gravity of up to three; flows suitable for their removal should be used wherever possible. The solid particles transported by the water move more slowly than the water itself, so at least twice the nominal volume of water in the section of main should be flushed.

Swabbing

Swabbing (see Section 4.4.3) may be used where only moderate flows are available; it is generally effective at removing loose deposits and burrowing animals, and can also remove lightly attached organisms such as aquatic gastropod snails. However, swabbing is not very effective in badly encrusted mains.

Air scouring

Air scouring (see Section 4.4.4) may be used where only moderate pressures are available; it will effectively remove virtually all loose deposits and attached animals. It is less affected by encrustation on the pipe walls than foam swabbing. However, air scouring is normally restricted to mains up to 200 mm in diameter, and it may exacerbate corrosion in corroding iron mains.

6.4.3 Chemical methods

Chlorine

The concentrations of chlorine or chloramines normally found in water leaving treatment works, and that would be acceptable to consumers, are not very effective against most of the animals found in distribution systems. There is evidence that the higher concentrations that may be applied during water treatment have some effect in reducing animal penetration through treatment (Evins & Greaves, 1979). The oligochaete worms (e.g. *Nais*) are susceptible to moderate concentrations of chlorine; free chlorine concentrations raised to 0.5–1 mg/l, carried through the distribution system, have been used for control (Sands, 1969). Occasionally, very high concentrations of chlorine or chloramines have been used to counter particular problems after disconnecting consumers. For example, 12 mg/l chlorine has been used to kill leeches in a small isolated section of distribution system (Smalls & Greaves, 1968) and about 70 mg/l of chloramines has been used to kill chironomid larvae in temporarily isolated tanks (Broza et al., 1998).

Pyrethroids

Natural pyrethrins and a synthetic analogue, permethrin, have been used very successfully to control *Asellus*, other crustaceans such as *Gammarus*, and chironomid larvae (Burfield & Williams, 1975; Abram, Evans & Hobson, 1980; Mitcham & Shelley, 1980; Crowther and Smith, 1982). Although permethrin is chemically distinct from pyrethrins, it shares a number of properties that are important in its use for controlling animals in water mains. Among these are a very wide margin between the concentration that is effective in killing a range of aquatic animals, and the concentration that is toxic when drunk by mammals. For both substances the dose commonly used is 10 µg/l, which has not been considered a risk to consumers (Abram, Evans & Hobson, 1980; Fawell, 1987). The WHO guideline value for permethrin in drinking-water is 20 µg/l in the third edition of the WHO *Guidelines for Drinking-water Quality* (WHO, 2004). Because this value does not represent a significant risk to consumers over protracted periods of exposure, there is a significant margin of safety in comparison to the short periods for which permethrin may be present in drinking-water due to its occasional addition for control of animals. However, it is important that the dosing exercise is carefully controlled and monitored.

As the concentration effective for controlling animals in water mains is highly toxic to fish, it should not be discharged to watercourses, and warnings should be issued to those who may be affected (e.g. aquaculture, fisheries, aquaria). In some countries, the addition of pesticides to drinking-water is now prohibited and this precludes the use of pyrethrins or permethrin. In countries where the use of these chemicals is permitted, a decision to use them should take into account the seriousness of the infestation to be controlled and the available capacity to plan, control and monitor the operation. A carefully controlled and monitored application of these pesticides makes intensive use of technically qualified staff, and causes appreciable disruption to the system. Thus, it is only likely to be worthwhile to combat serious infestations. Note that these compounds are not included on the list of pesticides recommended by the WHO Pesticide Evaluation Scheme (WHOPES) for application to drinking-water sources for control of mosquito larvae for public health purposes (i.e. to control the disease vector).[1]

The preferred method of application is to treat an area that is small enough to allow systematic unidirectional flushing to be carried out in about 24 hours. The area should be separated from adjacent areas by closed valves to prevent reinfestation from untreated areas. Metered districts generally provide a convenient area, with adjacent areas treated subsequently. Consumers are not

[1] WHOPES documents can be obtained on request from the WHO Pesticide Evaluation Scheme, Communicable Disease Control, Prevention and Eradication, World Health Organization, 1211 Geneva 27, Switzerland.

usually disconnected. The pesticide solution is injected into a main under pressure at a rate proportional to the water flow. This ensures that, initially, all water flowing into the area being treated is at the target concentration, typically 10 µg/l. The network served from the point of injection is subject to systematic unidirectional flushing to draw the pesticide through the whole system. Twice the calculated volume in each length of main should be flushed. The pesticide tends to leave solution very readily (because of adsorption onto pipe surfaces and deposits); thus, some loss is to be expected as the water flows through the distribution system. It is advisable to monitor the concentrations reaching various points in the network during the dosing exercise. After allowing 24 hours contact, the dosing is discontinued and the systematic unidirectional flushing exercise is repeated to remove dead or moribund animals, and to draw fresh water into the system.

Other substances

In the past, some workers have suggested the use of copper for the control of animals in water mains, including *Asellus* and *Nais*, but its use has not found favour because it may promote corrosion of iron mains.

6.4.4 Measures suitable for different groups of animals

Isopoda

Isopoda are commonly known as 'slaters'. One example is *Asellus aquaticus*, which may be up to 15 mm long, so is obvious to consumers. It adapts readily to conditions in water mains and clings tenaciously to pipe walls. In a survey by van Lieverloo (1997) in the Netherlands, it comprised about 80% of the biomass of animals flushed from hydrants. Most complaints are received when the adult organisms die following reproduction in spring; at other times, large numbers may be present in the pipes without causing complaints. Collingwood (1964) suggested that the best season for control is in spring, immediately before the peak in reproduction. *Asellus* is controlled most effectively by dosing with pyrethrins or permethrin, accompanied by unidirectional systematic flushing of twice the pipe volume (see Section 6.4.3). Smaller crustaceans such as *Cyclops* and chydorids often increase after removal of *Asellus* using pyrethroids (Smalls, 1965). Both foam swabbing and air scouring may achieve moderately good removal of *Asellus* in favourable circumstances: they may also remove more sediments and thus inhibit reinfestation by other species.

Amphipoda

Amphipoda are freshwater shrimps; for example, *Gammarus. Gammarus* are up to about 15 mm long, so are obvious to consumers. Although they may be widespread, they seem not to increase to the densities shown by *Asellus*. They swim and are more easily removed by physical methods such as flushing and swabbing than *Asellus*. They are also susceptible to pyrethroids.

Insecta

Insecta are wormlike organisms; for example, the larvae of chironomids. Some species may be up to 25 mm long and bright red so are obvious to consumers, but most are much less conspicuous. Most species are unable to complete their life-cycle in the distribution system. They are controlled by systematic flushing or swabbing, depending on the flows available. Attention should be given to penetration of larvae through treatment works, access of adults to treatment works and ingress of adults through openings in service reservoirs. For those species that can complete their life-cycle in the distribution system, infestations can be successfully controlled using pyrethrins (Burfield & Williams, 1975) and permethrin (Mitcham and Shelley, 1980), where the use of these chemicals is permitted.

Oligochaeta (true worms) e.g. Nais

Worm species common in water mains are small and slender (typically up to 7 mm long and 0.3 mm wide), but may be noticed when they swim. Other aquatic species may be somewhat larger. They can be controlled by unidirectional systematic flushing, swabbing or air scouring, with the free chlorine concentration raised to 0.5 mg/l throughout the distribution system for a few weeks. The maintenance of a residual of 0.2 mg/l or more is likely to prevent reinfestation.

Nematoda

Nematoda, commonly known as roundworms, are plant parasites, animal parasites or free-living organisms that feed on organic matter. Most, but not all, are invisible to the naked eye. Those found in water mains are not easy to identify but are thought to be mainly small free-living aquatic species, thriving in locations that are rich in organic detritus. They can be controlled by flushing, swabbing or air scouring.

Gastropoda (aquatic snails)

Many of the gastropoda (aquatic snails) that are prevalent in water pipes are small (e.g. 5 mm long), although some are appreciably larger. They cling to pipe walls, so are not effectively removed by flushing. Foam swabbing is effective in pipes that are not badly encrusted. Although specific molluscicides are available for agricultural use, none are known to be suitable for use in potable water supplies.

Smaller crustacea

Smaller crustacea include species such as *Cyclops* and *Chydorus*. The *Cyclops* that are common in water mains are mostly about 1.5–2 mm long, although some are larger. They may be noticed by consumers because they dart jerkily through the water. The chydorids are less than 1 mm long, and are not noticed individually by consumers. However, they may occur in very large numbers, and cast their carapaces frequently. These may become iron stained and be seen by consumers as discoloured water. In general, these crustacea can be controlled by systematic flushing if flows are adequate, or by swabbing or air scouring.

6.4.5 Long-term control measures

Long-term control measures are recommended to prevent animals reaching nuisance levels or, following disinfestation, to prevent recurrence of problems. The principal objective is to deny the animals a food supply and to restrict their entry into the distribution system.

Removal of particulate organic matter at treatment works

Probably the single most important step in limiting animal populations in mains is to minimize the quantity of particulate organic matter entering the distribution system. Many algae are suitable as food for filter feeding animals, and they comprise the bulk of particulate organic matter in water derived from impounded surface sources. Different treatment processes are best suited to removing different types of algae: the processes should be selected and optimized to take account of the types of algae present.

Removal of assimilable organic matter at treatment works

Assimilable organic material may contribute to the growth of microorganisms, and thus indirectly to the growth of animals. Processes should be selected and operated to minimize the quantity of assimilable organic matter leaving the works, as discussed in Section 2.3.3.

Removal of animals at treatment works

Virtually all works treating surface waters allow the passage of some animals, although the numbers may be very small when compared with those in the raw water, and do not account for the numbers found in distribution. In general, coagulation and sedimentation are not effective at removing animals. Slow sand filtration appears to give better removal than rapid gravity filtration. Planktonic species, which predominate in stored waters, are relatively easily removed by treatment and do not thrive in the distribution system. Benthic species, which account for a greater proportion of the raw water community in river waters, are more likely to pass treatment, and in turn are more likely to thrive in the distribution system. Organisms that are able to burrow in particulate media, such as chironomid larvae, nematodes and oligochaete worms, seem well adapted to penetrate treatment, and significant numbers of chironomids have been found at all stages of treatment.

It is unusual for animal removal to be made a specific objective in the management of treatment works. Nevertheless, attention to such things as the effectiveness of backwashing is likely to be beneficial in this respect. In rapid sand filters, particular care should be taken to eliminate "dead spots" where the sand bed is not effectively fluidised. Prechlorination has been shown to help the removal of animals: this benefit should be balanced against other considerations, such as formation of disinfection by-products.

Measures taken in the distribution system

Certain "good housekeeping" practices carried out in the distribution system will limit the potential for animal infestations. Service reservoirs should be covered. Ventilators on these reservoirs should be covered with 0.5 mm mesh to exclude flying insects, overflows should be fitted with nonreturn valves and inspection covers should be tightly fitting. Unused dead end mains should be eliminated where practicable, and the size of mains should be appropriate for the flows to be carried because slow-flowing water is conducive to precipitation of solids and to animal growth. Hygienic precautions should be taken when repairing mains. Water pressure should be maintained to discourage ingress and contamination. Mains and service reservoirs should be routinely cleaned to remove particulate matter.

6.5 SUMMARY

Any supply of water containing visible living animals or animal debris will discourage consumption and encourage the use of alternative supplies that may have a better appearance but may be less safe. Thus, for reasons of public health, it is important to prevent the entry and proliferation of animals in water distribution networks.

Regular monitoring of the populations of animals in distribution systems allows control measures to be applied pre-emptively. A number of measures are available for limiting the populations of animals in water distribution systems. Short-term measures are mostly based on methods for cleaning solid material from the pipes. Some chemical methods are also available; however, there are restrictions on the use of these in some countries. Their use should be carefully controlled and monitored, and this requires intensive use of technically qualified staff. Long-term measures are mostly based on limiting the quantity of organic matter entering the distribution system and prevention of entry.

A small number of studies have demonstrated the possibility that invertebrates may protect microorganisms from disinfection. Within a distribution system carrying well-treated water, the risk of a significant number of pathogens being protected in this way is thought to be extremely small. The risk posed by invertebrates protecting microorganisms from disinfection during their passage through water treatment works is also likely to be very small. This mechanism is relatively unstudied and little understood.

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