



THE HEALTH SIGNIFICANCE OF ANIMALS IN WATER DISTRIBUTION SYSTEMS

Final Report to the Drinking Water Inspectorate

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EXECUTIVE SUMMARY

There are rare occasions when the water delivered to consumers contains invertebrates and this has raised questions about the health risks which the presence of these animals represent. In these situations the Department of Health and the Drinking Water Inspectorate advise that whilst the presence of animals is aesthetically unpleasant there is no evidence of any risk to public health.

To provide a more secure basis for this advice, the Drinking Water Inspectorate contracted WRC to review the significance to health of animals in water distribution.

In reviewing the literature WRC sought answers to the following questions;

- are any of the invertebrates found in tap water pathogenic to humans?
- to what extent do aquatic invertebrates ingest and concentrate micro-organisms?
- how long do micro-organisms survive within aquatic invertebrates?
- do invertebrates excrete micro-organisms in a viable form?
- can ingestion of invertebrates potentially provide an infective dose of pathogens?

The review established that animal infestations of water distribution systems are associated with low flow rates and the presence of established biofilms. Three categories of animals are involved; those whose whole life cycle is completed in water (e.g. water fleas) and which may establish permanent populations, those whose life cycle is partially aquatic (e.g. insect larvae) which may survive for long periods, and terrestrial animals (e.g. earthworms) which are only transient inhabitants.

It was found that very few systematic investigations of the occurrence and concentration of animals in water distribution systems had been made and that there were even fewer studies of the microbiological aspects of these infestations. In the UK and other temperate climates it is unlikely that any of the animals would create a health problem. However, their mode of feeding is such that they will ingest, harbour and concentrate micro-organisms and there was some evidence that animals could contain opportunist pathogens, such as some *Aeromonas* species. Little information is available on the survival, or conditions which would encourage proliferation, of micro-organisms within the gut of the animals. There was general agreement that the animals afforded the micro-organisms with protection from the effects of water treatment processes, including disinfection.

Although the overall conclusion was that the presence of animals in water distribution poses little or no health risk to the population in general, it is possible that persons with impaired immune systems are at risk. Three suggestions have been made for studies which should provide the Department with more secure information on the microbiological implications of animal infestations.

This study was funded by the Department of the Environment and supervised by the Drinking Water Inspectorate.

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1. INTRODUCTION

1.1 Background

About one hundred and fifty species of animals have been identified within water distribution systems. They usually enter the system after passing through the water treatment plant, although some may gain access through areas of poor integrity or during maintenance or repair. Some species cannot complete their life cycle in the aquatic environment and thus their presence is only transient. However, others are able to survive and proliferate if sufficient nutrients are available.

Although treated water contains relatively low concentrations of organic carbon, the large volumes involved result in significant amounts of nutrients in a water distribution system. These nutrients support the growth of micro-organisms (bacteria, fungi and protozoa), which in turn form part of the food chain of invertebrates such as nematodes (round worms), *Asellus* (water louse) and chironomids (insect larvae).

Where large infestations occur, the presence of live or dead animals in the consumers' water may give rise to complaints about the aesthetic quality of the water and to concerns about risks to health. Local authorities or area health authorities occasionally refer such complaints to the Drinking Water Inspectorate or to the Department of Health. The advice given is that whilst the presence of animals constitutes an aesthetic problem, there is no evidence of any risk to the health of consumers.

The Department of the Environment wishes to establish whether the current assumption that the presence of animals in water distribution systems are an aesthetic problem, but there is no risk to the health of consumers is correct. As a consequence they commissioned a study with the objectives of:

- a) reviewing reports of animals in water treatment and distribution systems;
- b) assessing whether reported laboratory experiments are representative of water treatment and distribution conditions and whether laboratory results or field observations provide any substantial evidence of risk to consumers' health; and
- c) recommending whether further laboratory studies are required to establish whether animal infestations might constitute a risk to consumers' health.

The study was funded by the Department of the Environment and carried out under the supervision of the Drinking Water Inspectorate by WRc plc.

1.2 Approach used

Sources of information for the review were identified from WRc library catalogues and by searches of the Aqualine, Biosis Previews, Life Sciences Collection and Medline databases. The subject has been discussed with contacts in the water industry in the UK and also overseas and this was supplemented by a questionnaire sent to UK water undertakings.

To be able to evaluate the risk to consumers' health arising from animals in potable water the answers to the following questions were sought:

- How well do pathogenic bacteria, opportunistic pathogenic bacteria, viruses and pathogenic protozoa survive in water?
- Are any of the invertebrates pathogens?
- To what extent do aquatic invertebrates ingest and concentrate micro-organisms?
- How well and how long do micro-organisms survive within aquatic invertebrates?
- Do invertebrates excrete micro-organisms in a viable form into the water?
- Will ingestion of invertebrates potentially provide an infective dose of pathogens to the consumer?

The first question is beyond the scope of this review, but extensive reviews elsewhere (for example, McFetters 1990 and Gray 1994) show that many organisms can survive long periods in the aquatic environment. The remaining questions are addressed in the sections that follow.

Section 2 considers the types of animal which can be found in water distribution systems and reviews the incidence of infestations in recent years with particular reference to the UK. Information on the pathogenicity of these animals to man is reviewed in Section 3. What is known about the microbial content of animals is reviewed in Section 4 with the impact of disinfection being assessed in Section 5. In Section 6 an attempt has been made to assess the health risk to the consumer. Conclusions in the form of answers to the questions posed above are made in Section 7 and this also highlights the topics on which further information is needed. Three strategies for providing better information on the potential risks to health posed by animals in water distribution are described and discussed in Section 8.

2. ANIMALS IN WATER DISTRIBUTION SYSTEMS

2.1 Diversity of species

About 150 different species of macroinvertebrates have been reported in British water distribution systems. The biology and habitat of the more significant species have been described, together with illustrations, by Smalls and Greaves (1968) and by Sands (1969). The animals found in distribution systems can be classified into three broad categories.

2.1.1 Fully aquatic animals

The fully aquatic invertebrates are those which spend their whole life cycle in water.

The more common species observed in tap waters include: the water louse, *Asellus* sp., which at up to 15 mm long is quite obvious to the consumer. Slightly smaller is the fresh water shrimp, *Gammarus* sp. which reaches lengths of up to 13 mm. The segmented worms, *Nais* sp., reach lengths of 5-7 mm and are usually detected by their wriggling action. The small crustaceae, such as *Cyclops* or *Chydorus* species are not readily visible, being transparent and about 1.5 mm long, but they do have a characteristic darting motion.

Nematodes, (roundworms or eelworms), are common in water, but most species are too small to be seen by the naked eye.

Water snails (e.g. *Potamopyrgus* sp.) are very common in water mains, but because of their tenacity to cling to the pipe walls they rarely occur in tap water.

In addition there will also be present in mains and tap waters many microscopic protozoa and amoebae that may harbour bacteria and viruses.

2.1.2 Partially aquatic animals

This category comprises mainly the larval stages of insects, (chronomids) which vary considerably in size, ranging from 5 mm to 25 mm depending upon their species. Some are highly coloured, giving rise to the common name of blood worms.

2.1.3 Terrestrial animals

Earthworms, terrestrial snails and slugs can occasionally be found in water supplies. These animals do not have an aquatic phase in their life cycle, nor do they seek water, so their ingress into the system is accidental and consequently of a transient nature.

2.2 Entry into water distribution systems

The animals which successfully penetrate treatment processes and become established in the mains are largely benthic, or bottom dwelling, organisms such as some *Cyclops* and some *Nais* species. However, where the raw water is of good quality, such as that from an upland reservoir which requires little treatment other than microstraining and disinfection, free swimming plankton species, for example the waterflea *Daphnia*, may enter the distribution system.

At service reservoirs flying insects can gain access through unprotected vents and lay eggs on the water surface which hatch and release chironomid larvae into the water.

Cracks and poorly fitting manholes or keyholes at reservoirs can provide entry points for terrestrial animals such as slugs and earthworms. Inadequate working practices may also allow terrestrial animals to enter the distribution system during the laying or repair of water mains.

2.3 Colonisation of water distribution systems

2.3.1 Establishment of animal populations

Only those animals whose life cycle is wholly aquatic will be able to survive and reproduce to establish permanent populations in water distribution systems. These include, *Asellus* sp. (water louse), *Gammarus* sp. (freshwater shrimp), *Nais* sp. (segmented worms) and nematodes (roundworms).

Almost all insects require a non-aquatic phase to complete their lifecycle. Thus, although the larvae can be present in distribution systems in large numbers and may persist for some time, they generally are unable reproduce and establish a permanent population.

Terrestrial animals, such as earthworms and slugs, that gain access to distribution systems will not survive for a long period in the hostile aquatic environment.

Continual seeding of a distribution system with invertebrates could have an effect similar to the establishment of a permanent population. Persistent occurrence of animals, particularly larvae or terrestrial animals, is a strong indicator of a failure of the integrity of the distribution system.

2.3.2 Factors influencing population size

In any population the main factor controlling its size is the availability of food, although other factors such as the proximity of predators and local ambient temperature will exert some influence.

Water entering a distribution system will contain soluble organic material. The amount of organic material present will depend on the source of the water and the types of treatment and disinfection that have been applied. This soluble organic material, the lowest level of the food chain, is utilised mainly by bacteria and other micro-organisms. These in turn become the food source of the larger animals. These sources are supplemented by soluble and particulate material from the dead and decaying animals and other organisms that may be present in the mains. Active organisms further increase the food bank of others with their faecal and other excretions.

2.3.3 Location of colonies

Animal populations are generally largest in 'dead end' mains or where the flow is not great. The low flow not only enhances the deposition of particulate matter, it also reduces the disruptive effect of turbulence and scouring on the physical structure of the colony. The deposited material provides a source of food, a stable habitat and shelter from predators for animals in the lower levels of the food chain which in turn provides a static and readily available source of nutrients for the organisms higher in the food chain. Contacts within the Industry familiar with these problems comment that such colonies are more likely to occur in older parts of distribution systems constructed of cast iron pipes. They are rarely seen in areas where newer plastic pipes have been used.

2.4 Frequency of occurrence

There are no reports in the last decade of systematic studies of the occurrence of invertebrates in water distribution systems.

The general view, arising from discussions with contacts within the Industry, is that the number of incidents has decreased over the last 15 years. This is considered to be the result of control programmes using synthetic pyrethrins, mains rehabilitation schemes and better quality water entering the distribution system from improved treatment or better raw water sources. There is, however, some anecdotal evidence from similar sources that the number of incidents has increased in very recent years.

In an attempt to evaluate the position and to obtain up to date information, a short questionnaire was sent to each water supply undertaking in the United Kingdom. This sought information on the number of incidents that had occurred in recent years and the main invertebrates identified. The questionnaire is reproduced in the Appendix.

Replies were returned from 33 of the 42 water undertakings approached. Some 3625 incidents were reported. Most were cases of infestation of specific areas of the distribution system, but, because of differing methods of data recording by the undertakings, some reports were of the number of consumer complaints.

Twelve undertakings reported no incidents in recent years and of those that had experienced problems:

- 1 indicated a slight increase in the number of incidents in recent years;
- 2 indicated a very small number of incidents in 1991 and 1992 but none in the preceding 2 years or subsequently;
- 5 undertakings reported a decrease in the number of incidents in recent years; and
- 11 reported a fairly consistent number of incidents in recent years.

The animals involved were identified in about one-third of the incidents:

- 64 per cent were fully aquatic animals which spend their whole life cycle in water, e.g. *Asellus* sp. and *Nais* worms;
- 30 per cent were animals which only spend part of their life cycle in water, e.g. larvae; and
- 6 per cent were terrestrial animals.

A number of undertakings pointed out that animals were associated with only a small proportion (about 0.5%) of the water quality complaints.

3. INFECTION CAUSED BY ANIMALS OR THEIR PARASITES

There is no evidence that the macroinvertebrates likely to be found in water cause infection in man. There are, however, a small number of parasites of man that have a larval stage which develops in animals which may be found in water distribution systems. Because some stages of the lifecycle of these parasites are temperature dependent, they are predominately found in tropical or sub-tropical areas and the diseases they cause are not indigenous in the United Kingdom.

The most important of these parasites is the guinea-worm, *Dracunculus medinsis*. One stage of the development of the larvae takes place in the body of small crustaceae such as *Cyclops* and related species. If infected crustaceae are ingested, further development of the larvae into the adult worm takes place in the muscle of man. The adult worms can reach to a metre in length and eventually migrate through the skin to return to water. Whilst the presence of the worm is not debilitating to the patient, the action of the developing larvae can cause muscle damage, and ulcers may develop at the site of the worm's migration through the skin.

The larval stage of the cat tapeworm, *Spirometria* sp., also develops in small crustaceae. Further development may take place in humans ingesting infected invertebrates, where migration of the larvae may cause considerable tissue damage.

The larvae of *Schistoma* initially develop in water snails but are released into the water as free living cercariae. The cercariae can infect through the mucus membranes but usually do so by penetrating the skin during washing or bathing where they continue their development (shistosomiasis or Bilharziasis) or produce a localised dermatitis (swimmers itch) depending upon the species of the shistosome.

Some free-living amoebae of the genera *Nagleria* and *Acanthamoeba* have been known to cause encephalitis after penetrating the mucus membranes of patients, usually the patient had been swimming in polluted waters. These organisms require a water temperature of 30 °C to develop into the infective stage and therefore are unlikely to be present in water supplies in the UK.

There is now evidence that some cases of infectious keratitis, an inflammation of the cornea, caused by species of the genus *Acanthamoeba* have arisen as a result of the cleaning of contact lens with contaminated tap water rather than using approved cleansing fluids (Seal *et al.* 1995).

4. ANIMALS AS VECTORS OF PATHOGENS

4.1 Conveyance of pathogens

The diversity of the microbial flora of invertebrates is likely to be influenced by and reflect the microbial populations of their habitat. By the nature of their feeding habits the concentrations of micro-organisms in the gut of the invertebrate will be greater than in the water column. As the animals penetrate water treatment systems their microbial flora will be protected from the hostile processes of disinfection. The areas where accumulations of animals occur, such as 'dead ends', will also be the areas with the greatest accumulations of micro-organisms. Although few of these micro-organisms will be those normally considered to be pathogens there may be significant populations of 'opportunistic pathogens'. Opportunistic pathogens are organisms (e.g. *Aeromonas* sp., *Pseudomonas* sp.) that are not normally pathogenic to healthy individuals but may initiate infection in a debilitated patient such as the immuno-compromised.

Although invertebrates may, by the nature of their feeding habits, concentrate pathogenic micro-organisms in their gut, conditions will be such that the micro-organisms are unlikely to multiply for the following reasons:

- Viruses need to enter cells of specific hosts in order to replicate.
- The cysts of parasitic protozoa and the eggs of parasitic worms need to be within a suitable host to complete the reproductive phase of their life-cycle, although some, for example *Dracunculus*, may develop into a stage that is infective to man within their invertebrate host.
- Bacteria can multiply in suitable conditions outside the mammalian host, but pathogens generally need temperatures approaching those of the body temperature of mammals (37 °C).

However, some species of bacteria (e.g. *Aeromonas* or *Pseudomonas*) which are opportunistic pathogens are capable of growing at temperatures below 37 °C.

Whilst, in general terms, the invertebrate intestine is not a natural habitat for pathogenic micro-organisms, it must be remembered that the mammalian enteric pathogens have evolved mechanisms which make them resistant to digestive processes. For pathogens to be present in the invertebrates in significant numbers there must be relatively large numbers present in the water column. Although this may occur in poor quality source waters it is unlikely in distribution where good water treatment and disinfection is practised.

Protozoa and amoebae are likely to be present in potable waters, particularly when biofilms or similar material are present in the pipes, but their size is such that they are unlikely to cause aesthetic problems. However, there is a lot of evidence from non-potable waters, that in warm situations these organisms will ingest bacteria such as *Legionella*

species, which will survive and multiply (Barbaree *et al.* 1986; Lee and West 1991; Kikuhara *et al.* 1994). There are Codes of Practice relating to the management and maintenance of water systems in buildings to overcome these risks.

4.2 Microflora of invertebrates

The subject of the microflora of the gut of aquatic invertebrates has been comprehensively reviewed, with over 220 references, by Harris (1993). This review points out that there is contradictory evidence on the survival of micro-organisms in this environment, and that there are few studies relating to symbiotic relationships between the gut micro-organisms and their hosts. Different phyla of aquatic invertebrates have different gut structures and therefore may have different relationships with specific genera of micro-organisms.

Aquatic invertebrates are in an environment which readily allows the diffusion of nutrients in a soluble form and therefore they may not need micro-organisms as part of their digestive system in the same way as terrestrial invertebrates. As a consequence it is easier for non-indigenous micro-organisms to become established in the gut of the invertebrate as there is less competition for space and for food. However, Chang *et al.* (1969) found that that less than 1% of *Salmonella* sp. and *Shigella* sp. survived for 48 hours after ingestion by nematodes.

The review by Harris (1993) cites a number of studies on the identity of bacteria within aquatic invertebrates, and quotes *Vibrio*, *Pseudomonas*, *Flavobacterium*, *Micrococcus* and *Aeromonas* as being amongst the most commonly reported genera. Many of the species within these genera are opportunist pathogens of man. Harris does, however, point out that these results may be influenced by the techniques used. Most common bacteriological identification techniques have been developed for use in medicine and the techniques and taxonomy for bacteria that are not of medical importance is sparse.

4.3 Studies on microflora of animals in water distribution systems

Very few studies on the microbial flora of animals recovered from potable water systems have been reported in the last decade. The most comprehensive is that by Levey *et al.* (1986). Over a two-year period (1982-1984) these workers examined 264 samples of water from a distribution system fed from a service reservoir in Worcester, Massachusetts (USA). Their techniques did not distinguish between bacteria within the gut of the animal and those associated with its surface. No pathogens or coliforms were identified in the animal homogenates, although coliforms were present in the reservoir. They did, however, identify a number of species that may be considered to be opportunist pathogens in some circumstances, such as members of the *Aeromonas*, *Pseudomonas*, *Serratia* and *Staphylococcus* genera.

Copepods comprised 51% of the animal population; amphipods 17%; and fly larvae 15%. The levels of bacteria recovered ranged from 10^2 - 10^4 per animal (from the amphipods which were in the size range 3-10 mm) to 1-10 per animal (from copepods whose size were between 1 and 2 mm).

These workers also drew some tentative conclusions which included:

- that the association of bacteria and invertebrates is related to the size of the invertebrate and the complexity of its surface; and
- that invertebrates which browse in sediments, e.g. amphipods, would be exposed to higher numbers of bacteria than those living in the water column, e.g. copepods.

A two-year study of 36 distribution systems in the Netherlands has recently been completed (Lieverloo *personal communication*). The results are not yet published. These researchers believe that if good water treatment practices are used there is little risk to health from micro-organisms within invertebrates.

An unpublished study in Sydney (Australia) found faecal coliforms in the order of 10^2 per animal in the macerated bodies of sponges and snails recovered from reservoirs and distribution systems (Watts *personal communication*).

In a recent Italian study Lupi *et al.* (1995) have examined the gut flora of nematodes recovered from a drinking water supply. In worms from both the treated water and the raw water they found members of the Enterobacteriaceae group, but of genera generally considered to be non-pathogenic. The levels of these bacteria and heterotrophic plate count bacteria were significantly lower in worms from the treated waters than in those from the raw waters.

The average length of the nematodes was 45 μm . During winter sampling of the raw water an average of 250 (range 11-382) colony forming units (cfu) of heterotrophic plate count bacteria and 11 (3-22) cfu Enterobacteriaceae were found in the nematodes. The finished waters were sampled over a period of a year and the average counts were 6 (1-15) cfu and 2 (0-33) cfu per nematode for the heterotrophic plate count and Enterobacteriaceae respectively. No *Salmonellae*, *Vibrionaceae* or sulphite reducing *Clostridium* sp. were found in any sample, although the source water was polluted by domestic effluents and *Salmonellae* were known to persist there.

Arising from laboratory studies of bacterial-protozoan interaction in the presence of chlorine, Shotts and Wooley (1990) have speculated that the apparent spontaneous occurrence of coliforms in chlorinated waters may be due to their passing through the treatment processes within protozoa and subsequently being released.

4.4 Studies on invertebrates in other freshwater systems

In a study of the gut flora of the schistosome vector snail, *Biophalaria glabrata*, recovered from their natural habitats in the West Indies, Ducklow *et al.* (1979) found the dominant genera to include *Aeromonas*, *Enterobacter*, *Acinetobacter*, *Pseudomonas*, and *Vibrio*. The range of genera and number of organisms per snail differed between the sites of origin but, on average, the bacteria count was 7×10^5 per snail.

Klug and Kotarski (1980) reported the dominant bacteria in the gut of crane fly larvae to be Gram-negative and probably tolerant of aerobic and anaerobic conditions. The levels of bacteria observed were about 10^9 per mg (dry weight) of gut wall, but there was a large variation between animals.

The ecological relationship between bacteria and the surface of copepods from Chesapeake Bay (USA) or the Buriganga River (Bangladesh) was examined by Huq *et al.* (1983). Using electron microscopy these authors determined that some species of bacteria, e.g. *E. coli* and *Pseudomonas* sp. did not adhere to the copepod's surface, but their studies suggest that other species such as *Vibrio* sp. may adhere and multiply on the surface of the animal.

There are a number of reports, e.g. Lee and West (1991), and Kikuhara *et al.* (1994) of *Legionella* sp. multiplying within the protozoa, particularly in cooling towers. However, these bacteria do not multiply at temperatures below 20 °C.

5. EFFECT OF DISINFECTION

Disinfectants at the concentrations conventionally used in water disinfection have little effect upon the viability of invertebrates. Only one comprehensive and specific study of the effect of chlorine on micro-organisms within invertebrates in the context of water supplies has been reported (Chang *et al.* 1960). Using two strains of nematodes isolated from potable water and subsequently maintained in the laboratory, they demonstrated that these invertebrates would ingest *Salmonella* and *Shigella* bacteria by grazing and Cocksackie and Echo viruses from suspension. Small numbers (1% or less) of these micro-organisms survived in the nematodes in excess of 48 hours, but there was no evidence of viable organisms being excreted. The nematodes were extremely resistant to chlorine. Almost all survived a 120 minute exposure to a concentration of 2.5-3.0 mg l⁻¹ and 10-20% survived a concentration of 95-100 mg l⁻¹ for 15 minutes. There was virtually no change in the numbers of bacteria or viruses recovered from the animal gut after either exposure to a nominal chlorine concentration of 15 mg l⁻¹ for 2 hours or a nominal 95 mg l⁻¹ for 30 minutes.

In contrast, Smerda *et al.* (1971) in another disinfection study demonstrated that viable *Salmonella* may be excreted by nematodes.

Levy *et al.* (1984) mixed the amphipod *Hyalla azteca* with *E. coli* and *Enterobacter cloacae* before exposure to chlorine. Their subsequent studies did not distinguish between bacteria that remained on the invertebrates outer surface after washing and disinfectant neutralisation, and those recovered from the gut. About 2% of the *E. coli* and 15% of the *E. cloacae* associated with the amphipod remained viable after 60 minutes contact with chlorine at a concentration of 1 mg l⁻¹. The control studies showed that bacteria that had not been in contact with the amphipod declined to about 1% of their original concentration after a 1 minute exposure to the chlorine.

A number of pathogens and coliform bacteria were co-cultured with protozoa isolated from a reservoir and exposed to chlorine by King *et al.* (1988). Viable bacteria were recovered from homogenates of co-cultures that had been exposed to chlorine at CT values >50 times those that inactivated bacteria not cultured with the protozoa.

6. RISK TO CONSUMERS

There is little literature covering the relationship between aquatic invertebrates and micro-organisms and only a small part relates specifically to potable water treatment and distribution. Most investigations have been of an *ad hoc* nature of local interest or have been studies of relationships between specific animals and micro-organisms.

There is no evidence of large-scale infections in man directly or indirectly arising from the contamination of water supplies from invertebrate animals passing through treatment plant or entering water distribution systems by other routes. However, sporadic cases of enteric disorder are unlikely to be investigated thoroughly enough for the source to be identified.

There is little evidence to suggest that strict pathogens are disseminated by animals in water distribution systems, but much of the available data indicates that opportunist pathogens such as *Pseudomonas* sp. and *Aeromonas* sp. are regular inhabitants of the gut of invertebrates. These may pose a risk to the immuno-incompetent and those with other debilities. Tap water has been implicated as the original source of these organisms in cases of hospital acquired infection (Speller 1990).

The data that is available suggests that the ingestion of one animal would yield a dose of 10^2 - 10^3 micro-organisms to the recipient. This level could represent an infective dose, if they were all the same species, if they were all viable and if they were all released into the intestinal tract of the recipient.

Some forms of tape worm and some shistosomes may be passed on by the use of contaminated water for potable or toiletry purposes, but these are unlikely to occur in the UK because of the climatic requirements of the other host in their life-cycle. The free-living amoebae of the genera *Nagleria* and *Acanthamoeba* can cause encephalitis in patients but, as these organisms require a water temperature of 30 °C to be in the infective stage, they are unlikely to be present in potable water supplies in the UK.

The protozoa which support the survival of *Legionella* bacteria will be present in the water distribution system. Since the bacterium will not multiply at temperatures below 20 °C and is infective by inhalation, it should not be a problem in correctly maintained potable water systems, but the relevant codes of practice should be applied to the management of hot water systems.

Infectious keratitis, (infection of the cornea), has been caused by amoebae of the genus *Acanthamoeba* in tap water used for cleaning contact lens. Cleaning fluids are available containing disinfectants to control this organism.

The study of the literature has not produced a clear answer as to whether animals in water mains are indirectly a threat to human health. There is evidence that the presence of micro-invertebrates (amoebae or protozoa), which would not be visible to the consumer, may present problems.

It can be hypothesised that animals may be a foci of pathogens in small discrete aliquots of any water that may be consumed. However, because pathogens are unlikely to multiply in water distribution, this hypothesis is based on the assumption that relatively large numbers of pathogens have entered the water supply or that the animal was heavily contaminated (from the source water) and that water treatment has had little effect on its microbial content.

7. CONCLUSIONS

In the 'INTRODUCTION' to this report a number of questions were identified which needed to be answered if the risk to consumer's health from the presence of animals in potable water was to be evaluated.

It is clear from the review presented in Sections 2 to 6 of this report that there is insufficient published information to provide unequivocal answers to these questions. The answers given in this section are therefore offered as the best currently available. Finally in this section, an attempt is made to answer the question implied in the title of this contract, "Does the presence of animals in distribution systems represent a risk to consumers health?"

How well do pathogenic bacteria, opportunistic pathogenic bacteria, viruses and pathogenic protozoa survive in water ?

This question is beyond the scope of this review, but extensive reviews elsewhere (for example, McFetters 1990, and Gray 1994) show that many organisms, particularly the opportunistic pathogenic bacteria and some of pathogenic protozoa, can survive long periods in the aquatic environment.

Are any of the invertebrates pathogens?

With the exception of some species of *Acanthamoeba* that may cause keratitis, inflammation of the cornea in wearers of contact lens, it is unlikely that any invertebrates pathogenic to man would occur or survive in potable waters in the UK. In tropical and sub-tropical regions amoebae (*Acanthamoeba* sp. and *Nagleria* sp.), which can cause encephalitis, may be present in badly managed water distribution systems. The larvae of some feline tapeworms, that may also infect man, some shistosomes (bilhaziasis or swimmers itch, depending upon the species) and of the guinea worm (*Dracunculus medinsis*) develop in aquatic invertebrates, but these intermediate hosts require ambient temperatures higher than those common in the UK.

To what extent do aquatic invertebrates ingest and concentrate micro-organisms?

There is ample evidence that some protozoa will ingest bacteria and develop a symbiotic relationship. There is evidence that other invertebrates ingest pathogenic micro-organisms and opportunistic pathogens but it is unclear to what extent the micro-organisms are concentrated in the animal gut.

How well and how long do micro-organisms survive within aquatic invertebrates?

It is obvious from the available information that micro-organisms can and do survive within and on the surfaces of aquatic invertebrates, but the length of the survival period is not clear.

Do invertebrates excrete micro-organisms in a viable form into the water?

The possibility of the invertebrates contributing viable pathogens to the water column has not been widely considered, and the available evidence is contradictory.

Will ingestion of invertebrates potentially provide an infective dose of pathogens to the consumer?

It can be hypothesised that this situation may arise. However, such a hypothesis is based on the assumption that a large number of pathogens have entered and survived in the water supply or that a large concentration of pathogens ingested by the invertebrate in its previous environment have survived during passage through water treatment.

It is possible that some cases of legionellosis have been the result of the causative bacterium multiplying in amoebae or protozoa in water supplies within buildings. However, the growth range of these organisms is 20 °C - 45 °C, and the relevant codes of practice require that cold water supplies and hot supplies are maintained at temperatures outside of this range.

Does the presence of animals in a distribution systems represent a risk to consumers health?

- There is no evidence to indicate that any of the animals which can be present, transiently or consistently, in UK distribution systems are pathogenic, with the exception of the amoebae causing infectious keratitis.
- Although the animals in distribution systems can contain significant numbers of bacteria the probability that they would be a major cause of disease seems remote.
- There is a risk that the ingestion of animals containing pathogenic organisms could be the cause of isolated and sporadic cases of illness.
- In certain areas of the distribution system the accumulation of opportunist pathogens within invertebrates could pose a risk to the health of immuno-compromised members of the community.

8. FURTHER STUDIES

Because of the lack of published evidence the ability to state definitively whether or not the presence of animals in distribution systems constitutes a health risk to the consumer requires specific research. It is suggested that further research in one of the following areas is given consideration.

8.1 Prospective health studies

The prospective health records of volunteers in water supply areas with and without animal infestations could be compared by study methods similar to those developed by Payment *et al.* (1991) for their study of the incidence of gastro-intestinal disease.

Because the differences between the groups of participants are likely to be small such a study would:

- have to cover a number of geographic areas, requiring the co-operation of several water supply organisations;
- have a large number of volunteers over a long period of time, requiring motivation to sustain interest and maintenance of records;
- generate a large amount of non-positive data to be analysed.

8.2 Studies on real distribution systems

The second approach would be to study animal/micro-organism relationships in real distribution systems in which infestations are a regular occurrence. Through specific planning and targeting of micro-organisms of particular interest attempts would be made to build on the information provided by the small number of studies reported in the literature.

An essential prerequisite of the study would be to gain further information from the recent studies carried out in the Netherlands, Australia and Italy. The advantages and disadvantages of the techniques used in these studies would be assessed and the conclusion used in the design of an investigation of selected UK distribution systems.

It is envisaged that in this study animals would be recovered from distribution systems by netting during hydrant flushing and by the removal of biofilm from sections of pipe obtained during maintenance work carried out by collaborating water companies. The microbiological content of the animals recovered would be examined immediately and then following storage for varying periods of time in “clean” water. The impact of disinfectants, free chlorine and chloramine, on the microbial content of the animals would also be assessed.

The microbiological content of the animals would be measured in terms of the following organisms, total coliform bacteria, *E. coli*, sulphite-reducing *Clostridium* sp., *Aeromonas* sp., *Pseudomonas* sp., and heterotrophic bacteria. Consideration would be given to testing for the presence of specific pathogens such as *Cryptosporidium* and enteric viruses.

The results of the studies should provide answers to the questions concerning the likely microbial content of different types of animals in distribution, the stability of the microbial population and its tolerance to disinfectants. The studies would, however, be reliant on the co-operation of water utilities in terms of permission and assistance with hydrant flushing and provision of sections of used pipe.

8.3 Laboratory based studies

The third approach would be to study specific micro-organism/animal relationships in the laboratory.

These studies would focus on animals with a totally aquatic life-cycle. The animals would be harvested from a distribution system and then grown in the laboratory to provide sufficient test organisms for the programme of experimental work. It is envisaged that the animals would then be maintained in a series of small aquatic systems containing a "sediment" nutrient supply to which a range of micro-organisms had been added.

A range of microbial loadings of the sediments would be used to determine if this influences the rate or the magnitude of ingestion/colonisation of the animals. After a range of residence times a number of the animals would be transferred to a clean water system. Changes in the microbial content of the animals and the "clean" water would be studied to determine if flushing/cleansing from the animals or alternatively growth within the animal can occur. The influence of temperature and organic loading (as assimilable organic carbon) on these processes would be studied.

Where significant animal/micro-organism associations are established the impact of water disinfectants (free-chlorine, chloramine and ozone) on the microbial content of the animals would be assessed.

The micro-organisms used in the studies would be total coliform bacteria, *E. coli*, sulphite-reducing *Clostridium* sp., *Aeromonas* sp., *Cryptosporidium* and heterotrophic bacteria.

These studies would establish whether or not animals can take-up and harbour micro-organisms of public health significance from their original habitats and protect them from the inimical effects of water treatment. In addition, data on the likely stability of the microbial populations within the animals would be obtained.

The laboratory studies would provide data obtained under controlled conditions about the potential for animals which inhabit water distribution systems to ingest, harbour and protect micro-organisms of public health significance. Apart from obtaining examples of representative species the studies would be independent of the co-operation of the water utilities and the occurrence of infestations in water distribution systems.

8.4 Recommendations

Of the approaches outlined in Sections 8.1-8.3, the laboratory based studies described in Section 8.3 appear to offer the best option. Although these studies would not generate information directly on the potential risks to consumers, they offer a more certain outcome in terms of assessing the potential for animals to harbour micro-organisms of public health significance. There are greater uncertainties inherent in the other two approaches and the first of these represents a relatively expensive option.

The information obtained from the third approach would enable the Drinking Water Inspectorate and the Department of Health to support its advice to the consumer on the public health risks which animal infestations may or may not represent.

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APPENDIX QUESTIONNAIRE SENT TO WATER UNDERTAKINGS

To evaluate the current position and obtain up to date information on animals in water distribution, a short questionnaire, together with a covering letter was sent to each water supply undertaking in the United Kingdom.

IN CONFIDENCE

Contact Name

Company

Telephone

Fax

ANIMALS IN WATER MAINS

Has your company experienced any problems with animals in water mains in recent years YES/NO
(If 'no' still please return form)

Please indicate the number of incidents in each year

1989		1990		1991		1992		1993		1994	
------	--	------	--	------	--	------	--	------	--	------	--

For each year could you please indicate the number of incidents which involved the animals listed .

	1989	1990	1991	1992	1993	1994
<i>Asellus/Gammarus</i>						
<i>Nais</i> worms						
Nematodes						
Chironomid larvae						
Terrestrial animals						
Other (please indicate)						

Thank you for taking the time to provide this data.