Section I

Expert consensus

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Expert Meeting Group Report

1.1 BACKGROUND

Waterborne disease in both epidemic and endemic forms continues to occur in both developed and less developed countries. Concern for waterborne disease is dominated by pathogens transmitted by the faecal–oral route and by drinking-water. Waterborne transmission also includes diseases transmitted by faecal droplet inhalation (e.g., some adenoviruses) and exposure through contact (e.g., recreational and occupational). It is interconnected with the consumption of shellfish and other harvest fisheries outputs and through indirect exposure to water in foodstuffs when the water is used in irrigation, in food processing, or as an ingredient. Interactions that result in waterborne zoonotic infections are illustrated in Figure 1.1.

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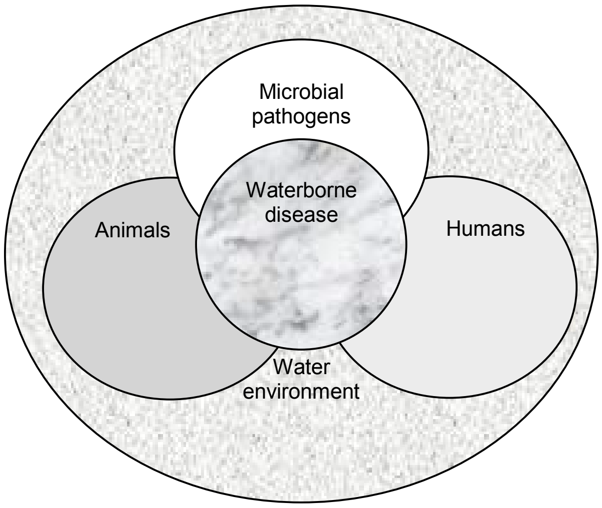

Figure 1.1. Waterborne disease interactions in the water environment.

It is important to place into context the zoonotic component of waterborne disease. Approximately 4 billion cases of diarrhoea occur each year, leading to nearly 2 million deaths. Intestinal worms infect more than a billion people worldwide. The percentage of these illnesses that are caused by zoonotic pathogens is difficult to determine due to a lack of data, but it is thought to be significant. Waterborne zoonotic pathogens cause both gastrointestinal diseases such as diarrhoea and other illnesses such as leptospirosis and hepatitis.

Some waterborne zoonoses are well known, information is limited on others, and it is likely that some, possibly many, remain unrecognized. Several waterborne zoonoses, such as cryptosporidiosis and giardiasis, occur regularly in a variety of countries; others, such as leptospirosis, occur more frequently in tropical countries. High quality information on many aspects of waterborne zoonoses is not available. There is also a need to better integrate the disciplines of human and animal health to anticipate emerging waterborne zoonoses and develop appropriate management responses to prevent them.

The phenomenon of “emergence” and “re-emergence” of infectious diseases in general is now well recognized. Up to 75% of emerging pathogens may be of zoonotic origin. A significant number of emerging and re-emerging waterborne pathogens have been recognized over recent decades. Many of these pathogens have zoonotic sources (e.g., *E. coli* O157:H7), and others have both human and zoonotic sources (e.g., *Cryptosporidium*). There are many pathogens for which there is currently no basis to confirm whether or not the strains implicated in human infection are from a human or an animal source. There is the added complication of multiple modes of transmission of certain zoonotic pathogens, including through food and secondary transmission.

The long-established World Health Organization (WHO) definition of zoonoses, “those diseases and infections (the agents of) which are naturally transmitted between vertebrate animals and man” (WHO/FAO 1959), was used in this meeting. However, by their nature, (re)emerging pathogens will have incomplete data, and adherence to such a strict definition should not exclude consideration of potential waterborne zoonotic pathogens because some component of their biology or life cycle is currently unknown.

1.2 FUTURE PERSPECTIVE

1.2.1 Driving forces

Available evidence suggests that (re)emerging zoonotic waterborne pathogens will continue to be recognized as being of significant and increasing public health concern due to a range of underlying driving forces. These include:

- changing patterns of water use;
- population factors, including growth, migration, and varying proportions of immunocompromised individuals;
- increasing travel and recreational activities;
- water scarcity, climate change, and severe weather events;
- conflicts and disasters;
- increasing urbanization and colonization of new habitats;
- increasing demand for animal protein and fresh vegetables in the diet;
- increasing use of antibiotics in animals and humans;
- increasingly concentrated animal husbandry practices and increased usage of concentrated feedlots;
- density of domestic pets;
- ecosystem disturbance; and
- international trade patterns in animals, animal products, and other foods.

A number of pathogen characteristics are important in the (re)emergence of zoonotic waterborne pathogens, including their capacity to adapt, mutate, or recombine in response to underlying driving forces such as those listed above and their capacity to acquire resistance to antibiotics.

The consequences of these driving forces strongly indicate that human exposure to zoonotic pathogens through water and the incidence of zoonotic disease are likely to increase. The impact of these factors will likely differ between and among developed and less developed countries. People without access to improved water supply and sanitation are at higher risk of contracting waterborne zoonoses. Populations with no access to improved water sources or with access to intermediate service will persist for the foreseeable future; for example, just to halve the proportion of people unserved by 2015, 2.2 billion additional people will need access to sanitation and 1.5 billion will need access to water in Africa, Asia, Latin America, and the Caribbean alone (WHO/UNICEF 2000).

Overall human population growth will continue. Urban populations of Africa, Asia, Latin America, and the Caribbean are expected to increase dramatically — Africa more than doubling, Asia nearly doubling, and the urban population of Latin America and the Caribbean predicted to grow by almost 50%. Additionally, populations themselves are changing, characterized by larger proportions of vulnerable subpopulations (e.g., very old or very young, pregnant, infected with human immunodeficiency virus [HIV]). Vulnerable groups may suffer higher rates of infection and more severe illnesses.

Urban agriculture, including the raising of livestock, is a growing phenomenon in many cities and may also increase human contact with animal excreta and abattoir wastes.

Urbanization is likely to lead to increasing populations of urban wildlife such as rats, foxes, skunks, possums, and other opportunistic species and increased human exposure to both feral and domestic animals. The implications of this for human health will depend on the amount of excreta that enters water resources, the nature and reliability of the drinking-water supply, the use of water for recreational or irrigation purposes, and the degree of contamination of water that supports harvest fisheries.

Population growth and (especially) affluence tend to increase demand for meat products. Increasing meat protein demand will likely be satisfied largely through intensified agriculture, particularly in less developed countries. Evidence suggesting that this leads to significant waterborne exposure is now becoming available (e.g., *Campylobacter* in New Zealand). The significance of water in the overall risks of zoonotic infection relates to its role not only in transmission directly to humans or through contamination of food, but also as a vehicle in the transmission to flocks and herds, thereby leading to increased overall environmental contamination and risk of human infection.

Affluence also leads to larger pet populations (including exotic animals). This increases the possibility that diseases carried by pets can be transmitted through water to people (e.g., infections from aquaria, such as *Comamonas* bacteraemia associated with keeping exotic fish or toxoplasmosis from cats).

1.2.2 Control strategies

Opposing the driving forces discussed in section 1.2.1 is the array of public and animal health and other interventions that can control adverse human health impacts. Health risks can be managed through source water protection, water treatment, water distribution, point-of-use treatment, and other interventions, such as vaccination (animals, humans, or both) or risk communication especially to susceptible populations. Source controls and close-to-source controls have particular significance, as they act on a range of known, potential, and unknown pathogens. The implementation of animal waste management systems is likely to lag behind the increase in intensified agricultural production, leading to increasing contamination of water sources and an increase in waterborne zoonoses.

Although (re)emerging pathogens are characterized by uncertainty and inadequate information, few potential zoonotic waterborne diseases present truly new challenges to waterborne disease control per se, and many can be indexed by better characterized agents. Benchmark pathogens that could be applicable to some of these situations include viruses (enterovirus, hepatitis A virus [HAV], and poliovirus), bacteria (*E. coli*), protozoa (*Cryptosporidium* and *Entamoeba*), and helminths (*Ascaris*).

A future challenge will be to better coordinate the efforts of professionals from the variety of sectors involved in human and animal health to anticipate emerging pathogens and reduce water-related transmission via effective control measures. It will be necessary to determine if current management strategies are protective of human and animal health or whether new approaches need to be developed and implemented. In the pursuit of the best use of limited resources for public health benefit, regulators, engineers, and other stakeholders require risk-based targets. The hazard analysis and critical control point/water safety plan concept should be applied to the prevention and control of waterborne zoonoses at all water cycle stages as well as to food products that may be exposed to waterborne zoonotic pathogens. For maximum beneficial impact on public health, management of waterborne zoonoses should be integrated into control of zoonoses through all routes, including food, contact, and water, and control of waterborne disease from diverse sources, as specified in the Stockholm framework (Bartram *et al.* 2001).

1.3 EVALUATION OF ZOONOTIC WATERBORNE PATHOGENS

There are a large number of pathogens potentially transmissible by the waterborne route. Among these are pathogens that are frequent or rare causes of human disease in any given "setting" and pathogens for which water may be a dominant or minor route of transmission.

The area of (re)emerging pathogens is one in which available information is incomplete. It is normally necessary to make assumptions and/or extrapolations or utilize analogies in order to make informed decisions. The degree of uncertainty makes it important to recognize that lack of information implies neither presence nor absence. In other words, lack of evidence does not mean that the pathogen does not exist in a certain region; instead, it may be the case that no one has looked for it.

There is a need for simple tools or criteria to discriminate among the many potential pathogens and to identify those of particular relevance to waterborne disease and its prevention. It is useful to distinguish between pathogens emerging because of increased recognition and those emerging because of increasing absolute or relative disease occurrence.

1.3.1 Approach

The credibility of any new or emerging zoonotic source of waterborne infectious disease must be established. The criteria for such a pathogen are twofold: first, the credible demonstration of a zoonotic phase, including those that may sporadically traverse species barriers; and second, the credible demonstration of a waterborne transmission route to humans. Several factors can be reviewed in order to determine whether a pathogen arising from an animal reservoir is a potentially significant emerging waterborne pathogen:

- pathogen adaptability;
- introduction into the environment;
- extent and proximity of animal reservoirs;
- persistence of pathogen in the environment and resistance to pollution control measures;
- human behaviour;
- outcome factors (infectivity, severity of adverse health impacts, human immune status); and
- public health factors (potential contribution of waterborne route to overall burden of disease).

These factors may be assessed by comparison with a "group benchmark" pathogen — a pathogen that has been well studied and for which effective control strategies have been developed. Such a benchmark organism must be one that is well documented in all aspects, including its interaction with the water environment. Viruses, bacteria, protozoa, and helminths are the minimum "groups" for which appropriate benchmarks are required (prions may be considered when more information on their fate and transmission becomes available). A simple system can then be used to compare a potential pathogen with locally relevant benchmarks. It should include a comparison with the benchmark pathogen for a particular factor (e.g., environmental persistence, resistance to chlorine disinfection). While subjective, such an approach could lead to a mechanism for prioritizing risk management decisions.

1.3.2 Pathogen adaptability

Specific factors may encourage rapid/accelerated evolution by pathogens. A well described example concerns the frequent use of antibiotics, leading to increased prevalence of multidrug-resistant strains of bacteria, which may then be introduced to human populations through waterborne and other routes. Viral mutations — such as those leading to the outbreak of severe acute respiratory syndrome (SARS) — and the capacity of some helminths to infect an increasing range of hosts indicate that such evolutionary trends are not restricted to bacteria.

1.3.3 Introduction to the environment

The likelihood that a pathogen will be transmitted through drinking-water, recreational water, or other routes is dependent on numerous factors.

Some of these reflect the characteristics of the pathogen itself, including resistance to environmental "stressors," such as ultraviolet light, desiccation, salinity, temperature, etc.

Along with trends in animal populations, the prevalence of a given pathogen (e.g., *Salmonella*) among animal populations may vary, and the intensity of shedding may be influenced by factors with their own underlying trends, such as the age of animal or seasonality.

There may be increasing introduction of a zoonotic pathogen to the water environment, arising, for example, from changes in control and management practices such as introducing sewage without treatment or through the land application of inadequately treated biosolids produced from agricultural processes. Contamination results from the discharge/runoff of untreated waste or inadequately treated wastewater into water bodies.

In some cases, pathogens have been brought into new geographic areas through the importation of infected animals (both livestock and exotic pets).

1.3.4 Extent and proximity of animal reservoirs

As described in chapters 11, 12, 24, and others, the density of animals (both domestic and wild) in a catchment basin is related to the amount of zoonotic pathogens that enter water sources. A pathogen that can infect a wide range of animals, both domestic and wild, may thus pose more of a challenge than a pathogen that infects only one host rarely present in a catchment basin.

Other factors concern the behaviour of the reservoir animals, the significance of which may vary widely between settings. Thus, pathogen carriage by, for example, urban rats, foxes, and other animals (including pets) may have limited significance where universal reliable piped water supply has been achieved, but it may be more significant where such a supply is absent or unreliable (as is the case for 1.1 billion people at present).

In some areas, it may be possible to manage pathogen reservoirs (both livestock and other animals) by excluding them from catchment basins or by preventing their contact with water (e.g., by installing fences to keep animals from entering rivers). Management of animals in catchments figures significantly in water safety plans implemented in Australia, for example (see WHO 2004 for more information on water safety plans and source protection).

1.3.5 Environmental resistance/persistence

Survival of zoonotic pathogens in water and the environment is a key factor in the transmission of waterborne zoonoses. Many zoonotic pathogens of concern (e.g., *Cryptosporidium*, *Giardia*, *E. coli* O157:H7) can survive for months in the environment under the right conditions. This increases the probability of waterborne transmission. In some cases, pathogens may be able to regrow in the environment (e.g., *Salmonella* has been shown to multiply in the natural environment; see chapter 14).

1.3.6 Human behavioural factors promoting exposure

Human behavioural factors include travel, migration, development of agricultural land, consumption of new food sources, new modes of food preparation, cultural factors, and reuse of wastewater. Migration of humans into undeveloped areas and clearing land for agriculture lead to increasing contact with animals, thereby potentially enhancing waterborne zoonosis risk. The human population is predicted to double between 1990 and 2015 — most of this growth will occur in less developed countries. Rural populations moving into urban areas in search of work, farmers bringing livestock into urban areas, and urban areas expanding into rural areas will all affect potential zoonotic disease foci.

1.3.7 Outcome factors

The primary interest is whether the agent is associated with human disease, as illustrated by the potential for hepatitis E virus (HEV) transmission from porcine reservoirs through water to humans. A range of factors, including age, differential infectivity, dose–response, and genetic differences in susceptibility, come into play when evaluating the outcome of an infection. Immunity in the population (i.e., due to vaccination or previous exposure) varies widely in and between developed and less developed countries. In addition, populations with high or low circulation patterns may interact with the differential levels of immunity to contribute to spread of disease. Malnutrition and the incidence of other diseases will also contribute to human susceptibility to waterborne zoonotic infections. In many areas, an increasingly large percentage of the population is considered to be vulnerable due to age, disease, pregnancy, etc. (see discussion in chapter 4).

It is also necessary to compare pathogens with one another in order to consider their relative public health significance. A pathogen causing self-limiting diarrhoeal disease with a low case fatality rate (e.g., *Cryptosporidium* in developed countries in non-immunocompromised persons) is clearly of lesser priority than one causing more severe disease requiring medical treatment (e.g. *E. coli* O157:H7) or one associated with delayed sequelae (e.g., *Campylobacter*, associated with Guillain-Barré syndrome) or with a high case fatality rate (e.g., *Cryptosporidium* in immunocompromised patients or HEV in pregnant women). In making these comparisons, it is essential to take account of locally specific vulnerability factors. Among these, immunosuppression (especially due to HIV infection and immunosuppressive treatment) is important and increases the importance of the availability of clinical treatments. Other infections may depend on factors such as age of first exposure (some, such as HAV, are relatively minor when acquired young; others, such as *E. coli* O157:H7, present more severity in childhood).

Combined consideration of these factors has been facilitated by the development and increasing application of metrics, especially disability-adjusted life years (DALYs) (WHO 2004). It is possible to estimate a DALY score for an "average" disease course for a given pathogen in specific circumstances and thereby compare it with a chosen benchmark. For simple scoring purposes, more/similar/less severe than the selected benchmark may be useful. Local factors such as access to health care facilities have an important impact on disease control and thereby DALY "scores."

1.3.8 Public health factors

Health risks from waterborne zoonoses should be seen in the context of the overall level of gastrointestinal (or other) disease within a given population. WHO has developed a harmonized framework for the development of guidelines and standards for water-related microbiological hazards (Bartram *et al.* 2001; see chapter 28). This framework involves assessing health risks prior to the setting of health targets, defining basic control approaches, and evaluating the impact of these combined approaches on public health status. Future WHO water-related guidelines are being developed in accordance with this framework.

For a given pathogen, the waterborne route of transmission may be of either limited or overwhelming importance. Thus, for example, where drinking-water is routinely disinfected, salmonellae are unlikely to be significantly distributed by this route; thus, salmonellosis is largely a foodborne infection in well managed water supplies, although waterborne transmission may occur where safeguards break down. It is inappropriate to extrapolate this conclusion to the areas where drinking-water safety is unsure. Local factors must be taken into account in determining whether a pathogen is likely to contribute a minimum of, for example, 5% of total disease transmission from waterborne routes; outbreaks and sporadic cases may need to be considered separately.

1.4 PATHOGEN GROUPS

1.4.1 Viruses and prions

Viruses demonstrate considerable host specificity. The direct human health significance of animal viruses with close human relatives (e.g., HEV in humans and pigs) remains unclear. However, their existence may suggest a historic process of crossover between species. A recent example of crossover is SARS, for which faecal droplet transmission appears to have been likely in some, albeit unusual, settings. Animal viruses with close human relatives, including some caliciviruses, coronaviruses, enteroviruses, picornaviruses, and rotaviruses, and specific viruses, such as HEV, coxsackievirus B5, and Nipah virus, may warrant further research and monitoring for their potential as waterborne zoonotic pathogens.

With respect to prions, bovine spongiform encephalopathy and chronic wasting disease should also merit further investigation as potentially waterborne zoonotic pathogens.

1.4.2 Bacteria

There are several well documented waterborne zoonotic bacterial pathogens, including *Salmonella*, *E. coli* O157:H7, *Campylobacter*, and *Yersinia*. The prevalence of these organisms depends on the nature of the source and the water supply, excreta and other waste disposal processes, and other environmental and climatic factors. Bacteria are a versatile group; their capacity to adapt to the varying conditions that result from the interaction of different driving forces is well recognized. In addition to continued research on the bacteria mentioned above, *Mycobacterium avium* (ssp. *paratuberculosis*) and *Leptospira* may warrant increased investigation and monitoring.

1.4.3 Fungi and microsporidia

Fungi are not normally considered as zoonotic waterborne pathogens. However, there is a significant range of both yeasts and moulds that are zoonotic, including *Trichophyton* spp., *Cryptococcus*, and *Coccidiodes*. Generally transmitted by contact, ingestion, or inhalation, credible waterborne routes may at some stage be demonstrated.

Four species of microsporidia have been found in a wide range of animals as well as in humans. They are commonly found in surface waters, and one suspected waterborne outbreak was reported in Lyon, France. Previously considered to be protozoans, molecular techniques suggest that microsporidia are more likely to be fungi.

1.4.4 Protozoa

Protozoan pathogens originating from animal and human waste have been recorded from water sources throughout the world. A number of well documented waterborne zoonotic protozoa exist, including *Giardia intestinalis*, *Cryptosporidium*, *Toxoplasma gondii*, and *Entamoeba histolytica*. There are other potential candidates, including *Cyclospora*, where waterborne transmission has been demonstrated but a zoonotic route remains to be established.

1.4.5 Helminths

Zoonotic waterborne helminth infections, including those caused by *Ascaris lumbricoides* and *Trichuris trichuria*, account for millions of human cases worldwide. There are also emerging helminthic parasites, some of which may occasionally be transmitted by water from a zoonotic reservoir. In most parasites, only one host is required for completion of the life cycle, and there is usually strong host specificity. Increasingly, multiple host susceptibility is being recognized, enhancing the likelihood of zoonotic waterborne transmission. In some helminthic parasites, the human host may be only one of several satisfactory hosts. Humans may become only incidentally involved, while animals act as the reservoir for the parasite. Evidence suggests that *Fasciola hepatica* may have significant transmission through drinking-water in some geographic regions. More research and monitoring of this parasite are warranted.

1.5 EXPOSURE/TRANSMISSION ROUTES

Excreted material and other animal waste products are the predominant sources of waterborne zoonotic pathogens. The pathogens use these materials as transport vehicles from the animal reservoir to the particular water environment, where their stability in that environment will influence the infectivity and thereby the risk to humans. The key concentrated sources of the pathogens are therefore:

- wastewater/biosolids from municipal and agricultural processes;
- faeces;
- urine; and
- carcasses and abattoir waste.

Zoonotic pathogens cross the species barrier from vertebrate animals to humans; the waterborne transmission route is one route of waterborne transmission. Water-related disease transmission routes have been described by a number of authors, introducing the concept of waterborne infections, water-washed infections, water-based infections, and infections with water-related insect vectors. The inhalation of contaminated aerosols and ingestion of foods (e.g., shellfish) that have been in contact with contaminated waters are also important. In the following list, the principal vehicles of transmission of waterborne zoonotic pathogens are described:

- drinking-water;
- water contact;
- water used in food preparation, production (including agricultural produce and seafood products), and processing; and
- aerosolized materials.

Identification of the sources and transmission routes of waterborne zoonotic infections is essential for developing and implementing appropriate control mechanisms (see chapters 5, 24, 25, and 26).

1.6 CONCLUSIONS AND RECOMMENDATIONS

The state of the evidence concerning waterborne transmission of zoonotic pathogens is incomplete but suggests that waterborne zoonoses pose a significant threat to public health in many countries. To better control threats to public health from waterborne zoonoses, both now and in the future, the expert group made the following conclusions and recommendations:

- People without access to safe water and sanitation are the most likely to suffer from waterborne zoonoses. Accelerating efforts to increase access to safe water and sanitation would have dramatic beneficial health impacts for a significant portion of the world's population.

- There is a need for a risk-based approach to setting standards for waterborne zoonotic infections. The group recommended that WHO take an active role in the development of evidence-based guidance for treating animal waste. This guidance should promote investigation of cost-effective technologies to meet management targets for different situations.

- Further efforts are needed to develop networks and facilitate regional cooperation that lead towards international harmonization for control of zoonotic pathogens across multiple exposure routes (water, food, contact).

- There is inadequate information on differentiation of human versus animal strains of human pathogens, both in the field (e.g., pathogen typing and microbial source tracking in order to orient control activities to priority concerns) and analytically (e.g., relative infectivity and pathogenicity). Both of these areas are priorities for targeted research.

- Improving understanding is important in harmonizing approaches to waterborne zoonoses. Currently available surveillance data, on both sporadic and outbreak diseases, are of limited use in understanding the importance of zoonotic waterborne infection. Surveillance for waterborne disease in general and waterborne zoonoses in particular has failed to provide a meaningful indication of the associated burden of disease, even in countries with established systems.

- Efforts are needed to devise tools, systems, and management responses to support outbreak investigation and response and to establish effective water-related disease surveillance.

- Anticipatory, "horizon-scanning" perspectives are a key to identifying (re)emerging waterborne zoonoses, as well as identifying new animal diseases, investigating their capacity to be zoonotic, and determining their capacity to be waterborne. Such "horizon scanning" can be successful only if appropriate organizational structures representing both animal and public health sectors are established.

- Molecular biology is a key technology for the future and is currently essential for the characterization of all zoonotic pathogens. However, there is a continuing need for reliance on traditional techniques of identification for many pathogens. This is particularly true for developing countries that are in need of quick, accurate, low-cost analytical tools that can be applied in remote areas. Research on real-time treatment process indicators related to pathogen removal in a range of technological situations is also needed.

- The importance of cross-sector and interdisciplinary collaboration between sanitary microbiologists and engineers, veterinary scientists, and agricultural scientists and engineers in controlling waterborne zoonoses cannot be understated. Networks and regional cooperation continually arise as cross-cutting themes and must be established. Evidence of situations where collaboration could have mitigated the impact of emerging waterborne zoonotic pathogens is amply available in the cases of both cryptosporidiosis and campylobacteriosis. Funding will be more effectively directed should the creation of such coordinating bodies occur, incorporating an appropriate range of different expertise.

1.7 REFERENCES

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