4.4 Water-borne diseases and climate change

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Summary

- The epidemiological study of possible links between climate change and water-related disease is at an early stage. Information on long-term trends and further research are needed to make reliable predictions about the climate effects on water-related health. It is important to note that the health effects are not confined to infection, although this section focuses on water-related pathogens.
- The evidence is at present mainly based on seasonal variation in water-related infections: most organisms show strong seasonal cycles with timing of peaks of water contamination related to latitude (especially *Campylobacter*) and possible response to seasonal changes in temperature and rainfall (especially *Cryptosporidium*).
- No convincing evidence of either drought or flooding effects on the incidence of water-related organisms exists in the UK, possibly because of good water and sanitation infrastructure and management, amongst other factors such as climate and prevalence of pathogens. The absence of 'drought' or 'flood' associated infections in the UK contrasts with experience in other countries, particularly those with less-secure sanitation structures.
- Travel-related water-borne infections are relevant to UK estimates of climate change effects on health, because of an increasingly mobile population and overseas exposure.
- There may be a need for increased attention to the quality of water in swimming pools and of bottled water quality both at home and abroad.

4.4.1 Introduction

Climate change may affect our water supplies in terms of quality, quantity and availability. Evaporation is likely to reduce fresh water resources, with the additional influence of salt water incursion due to higher mean sea levels. Reduction in ground water will affect aquifer water resources and force greater dependence on surface waters, which have higher levels of contamination. Chemical contamination is also likely to increase due to less dilution of industrial pollutants. The likely increased incidence of extreme weather events poses a threat to water supplies and the potential for contamination by means of flooding, increased run off and damage to water and sewage treatment works. Higher mean temperatures of surface water, and increased nutrient load, will promote the growth of cyanobacteria, causing algal blooms. Finally, upland sources from peat covered catchments are likely to contain enhanced levels of dissolved organic carbon, particularly when re-wetting follows drought periods, producing risks of trihalomethane formation on disinfection with chlorine[1].

The health problems associated with these changes will depend on a number of factors:

- the degree to which UK water quality can be maintained;
- the speed of climate change and the associated incidence of extreme weather events; and
- behavioural and adaptive factors.

Water-related behaviour is likely to be strongly affected by climate change, for example warmer summers are likely to lead to an increase in the recreational use of water and increased water consumption. At present, there is very limited information on the way changes in average temperature and precipitation will affect the biosystems that determine the distribution and viability of micro-organisms capable of producing disease. There is also very little information of the association of climate parameters with the incidence of human and animal water-borne infection. This section summarises the epidemiological issues in investigating water-borne disease, the evidence of a link to climate variation, the potential effects of climate on water-related disease and the research required to make further progress.

4.4.2 The epidemiological challenge in attributing water as a cause of disease

The WHO[2] international definition of water-related disease is as follows:

> *Water-related disease is defined as any significant or widespread adverse effects on human health, such as death, disability, illness or disorders, caused directly or indirectly by the condition, or changes in the quantity or quality, of any waters. The causes of water-related disease include micro-organisms, parasites, toxins and chemical contamination of water.*

Current methods of ascertaining water-related disease

In the UK at present there is no statutory mechanism for reporting water-related disease, in contrast to food poisoning. The latter includes gastrointestinal infections of unknown aetiology as well as those where a water based aetiology is suspected or confirmed. How much water-related disease contributes to current levels of food poisoning is unknown. Water companies are required to report incidents that might present a risk to public health to the Drinking Water Inspectorate, to local authorities and to area health authorities. The Inspectorate publishes its assessment of incidents and any outbreaks of drinking water-related illnesses in its annual reports. The uncertainty in attributing cause in water-related disease suggests that water-related disease may be under reported and that it may be frequently unrecognised.

The attribution of disease to a water source is complicated by the fact that so many organisms can be transmitted by water, but most also have other vehicles such as person to person spread. It may be difficult or impossible to confirm a suspected water link for sporadic cases and small clusters. For example, the association of *Cryptosporidium spp.* with water has been established for several large outbreaks, but research and surveillance data on the causes of sporadic cases of *C. parvum* suggests that animal contact may be a more important risk factor[3]. Similarly, epidemiological studies of water outbreaks, particularly those involving private supplies, have implicated *Campylobacter spp*.[4,5], but the cause of most sporadic cases of campylobacter enteritis remains obscure.

With other types of disease associated with the environment, epidemiologists have been able to apply various criteria to attribute cause. For example, the nine criteria proposed by Bradford Hill[6] can be only rarely fulfilled, for both practical and ethical reasons. The first of these criteria, strength of association, has been used to assess reported water-related outbreaks of disease in England and Wales. Using evidence such as identification of the same organism in the water and in human cases, results of analytical epidemiological studies and of documented water treatment failure, outbreaks reported to the Communicable Disease Surveillance Centre (CDSC) have been classified as ‘strong’, ‘probable’ and ‘possible’[7] (Table 4.4). The outbreaks known to CDSC and the strength of association are reported at six monthly intervals. Most of the reported outbreaks are investigated by descriptive, rather than analytical, epidemiological techniques.

Table 4.4 Infections associated with water

Disease	Organism	Mode of transmission	Areas of risk
Aeromonas associated diarrhoea	*Aeromonas spp.*	Consumption/exposure to contaminated water	Worldwide
Amoebiasis	*Entamoeba histolytica*	Faecally contaminated water or case to case	Tropics; areas of poor sanitation & institutions
Amoebic meningo-encephalitis	*Acanthamoeba/ Naegleria*	Exposure to contaminated water	Worldwide: water the main reservoir. Fountains/spas
Campylobacter enteritis	*Campylobacter jejuni*	Contaminated water; chicken/pork; animal contact; case to case transmission very uncommon	Worldwide: carried by many animals and birds. Private or institutional water supplies in UK
Cholera	*Vibrio cholerae 01 / 0139*	Faecally contaminated water	Most continents, including S.E. Europe. Natural reservoir in estuarine waters – shell fish association
Cryptosporidiosis	*Cryptosporidium parvum*	Faecally contaminated water, animal contact	Worldwide: human and animal reservoirs
Cyclosporal enteritis	*Cyclospora spp.* (coccidian parasite)	Faecally contaminated water	Asia, S. America, Caribbean
Dermatitis/ diarrhoea related to blue green algae	Toxins of *Cyanobacteria spp.*	Exposure in freshwater lakes/estuaries; also via consumption of water/ fish	
Diphyllobothriasis	*Diphyllobothrium latum*/other species	Consumption of raw/ undercooked fish from lakes	Subarctic, temperate and tropical zones
Dracunculiasis	*Dracunculus medinensis* (Guinea worm)	Consumption of water containing *Cyclops* larvae	Tropics
Fascioliasis	*Fasciola hepatica*	Consumption of uncooked aquatic plants bearing encysted forms e.g. watercress	Sheep and cattle raising areas in the Americas, Europe, Middle East, Asia and Africa
Giardiasis	*Giardia lamblia*	Faecally contaminated water; case to case	Worldwide; areas of poor sanitation

Disease	Organism	Mode of transmission	Areas of risk
Haemorrhagic colitis	*Escherichia coli O157:H7/ verotoxin producing E.coli*	Faecally contaminated water	Probably worldwide: identified in N. America Europe, S.Africa, Japan S. America and Australia
Hepatitis (viral)	*Hepatitis A*	Mainly case to case: also consumption of contaminated water/ shellfish	Worldwide
Leptospirosis (Weil's disease)	*Leptospira interrogans* serovars	Exposure to contaminated water	Worldwide except polar regions
Melioidosis	*Pseudomonas pseudomallei*	Contact with water contaminated by the saprophyte	S. E. Asia, S. America
Microsporidiosis (dermatophytosis + gastroenteritis)	*Microsporidium spp.*	Exposure to contaminated water	Worldwide
Mycobacterial granuloma	*Mycobacterium marinum*	Contact e.g. swimming in contaminated water	Worldwide; association with keeping tropical fish
Schistosomiasis (Bilharziasis)/ Swimmer's itch	*Schistosoma haematobium* & other species	Contact with free swimming cercariae	Tropics
Shigellosis (bacillary dysentery)	*S. dysenteriae*	Faecally contaminated water: case to case	Areas of poor sanitation
Streptobacillosis (rat bite fever)	*Streptobacillus moniliformis*	Water contaminated by rat urine	Worldwide, uncommon in N. Europe/N. America
Tularaemia	*Francisella tularensis*	Exposure to contaminated water (but mainly arthropod-borne)	Temperate zones: N. America, continental Europe, China, Japan
Typhoid fever	*Salmonella typhi*	Faecally contaminated water	Areas of poor sanitation
Viral gastroenteritis	*SRSV, enteric adenoviruses, rotaviruses, cytopathogenic enteroviruses*	Faecally contaminated water (but mainly case to case)	Worldwide

Table 4.5 Criteria for estimating strength of association between human illness and water

Criteria	(a) the pathogen found in human case samples was also found in water samples (b) documented water quality failure or treatment failure (c) significant result from analytical epidemiological study (case-control or cohort) (d) suggestive evidence of association from a descriptive epidemiological study
Strength of association	(a) + (c), (a) + (d) or (b) + (c) (b) + (d), (c) only or (a) only (b) + (d)

Acute versus long-term water-related disease

There is little known about the long-term effects of exposure to unwholesome water, or of the possible links between chronic disease and exposure to contaminated water at an earlier time. Long-term effects have been postulated, particularly following chemical incidents, and also for *Campylobacter, Helicobacter pylori* and cyanobacterial exposure by means of water, but as yet no long-term, prospective studies have been undertaken.

Types of water covered by surveillance

The types of waters included in the surveillance of water-related disease include surface waters (rivers, lakes), ground waters (any water in underground strata and boreholes), enclosed waters (artificially created bodies of water separated from surface freshwater or coastal waters, including those inside buildings) and sanitation (collection, transport, treatment, disposal and reuse of human excreta through collective systems or small installations). From the risk assessment perspective, public health practitioners need to be aware of the main contaminants in local waters, including industrial pollutants as well as of the infection risk from livestock. The risk appraisal must also include enquiring about infrequently used supplies, change in use of supplies or supplementation of a public mains supply with water from a private well. Many institutions, including hospitals, have a private well and some rely on this type of source or use it to supplement a mains supply.

Drinking water: definitions

Water intended for drinking is subject to vigilant surveillance and, in many countries for example the UK, is controlled via a separate government agency. 'Drinking water' refers to wholesome, clean and safe water intended for consumption by humans. Wholesome water is defined by reference to the standards laid down in the Water Supply (Water Quality) Regulations, 1989. Such water should be free of any micro-organisms and parasites and any substances, in numbers or concentrations, which constitute a potential danger to human health. It includes water used in food preparation and as a constituent in foods. Pollution of water indicates the presence or introduction of products of human activity which have harmful or objectionable effects. In the Dangerous Substances Directive (76/464/EEC), water pollution is defined as the discharge by man, directly or indirectly, of substances or energy e.g. heat into the aquatic environment, the results of which are such as to cause hazards to human health, harm to living resources, to aquatic ecosystems, damage to amenities or interference with other legitimate uses of water. Water contamination differs from the definition for pollution in that the levels present may not necessarily cause harm.

Existing evidence of the effects of climate on water-related disease

The international definition of diseases associated with water refers to water-related, rather than water-borne disease. The latter implies consumption of water, while disease may occur from direct exposure to contaminated water or through exposure to vehicles contaminated by unwholesome water. It includes 'water-washed' diseases related to poor hygiene consequent upon unsafe or insufficient water supplies: examples include Hepatitis A and bacillary dysentery and fungal skin infections or eye infections, such as trachoma. It is important to remember that such diseases may be increased by a lack of water rather than contamination of water. It also includes diseases related to waste water, 'grey water' (recycled) and solid waste disposal where there is a potential for water contamination. The definition also encompasses disease related to chemical contaminants, which may be by direct consumption of drinking water or exposure during swimming or washing.

Infections associated with water include several which are now mainly confined to tropical zones and areas of poor sanitation (Table 4.4). Those of emerging importance such as *C. parvum, Campylobacter spp.* and *E.coli O157* are common in the UK and other parts of Europe[8], although most reported infections with these organisms are not known to be water-borne. Microsporidia have received recent attention, following a report from France of intestinal microsporidiosis associated with water in 1995 and concerns, similar to those about *Cryptosporidium spp.*, of risks to people with damaged immune systems. While immune deficiency is a strong risk factor, microsporidial infection also occurs in the absence of any apparent deficiency. Two species of microsporidia are commonly associated with diarrhoea: *Enterocytozoon bieneusi* and *E. intestinalis.* The source may be farm animals and *E. bieneusi* has been identified in surface water, while *E. intestinalis* and other species have been identified in tertiary sewage effluent. Temperature rises may favour the survival of microsporidia in the environment and hence pose a greater risk of faecal-oral transmission by means of water supplies. As with other spore forming protozooal infections *(Cryptosporidium spp., Giardia spp.)*, disinfection with chlorine is relatively ineffective and other forms of water treatment are required to destroy microsporidia.

In addition to infections acquired by consumption or by direct exposure, many others are water-associated in that water plays a part in transmission or in environmental survival of the reservoirs of infection. Examples include legionnaires' disease and malaria. The incidence of both infections is likely to increase due to:

- climate effects on the mosquito vectors of malaria;
- increased use of air conditioning and humidifiers in hot summers and warm climates (travel related legionnaires' disease); and
- increased travel and exposure in high risk areas.

A detailed discussion of the possible effects of climate change on malaria in the UK is provided in Section 4.3. Many pathogens survive in water, but this is not necessarily the most efficient vehicle of transmission. For example, small, round structured viruses are relatively chlorine resistant and survive in water following sewage discharge or in moist environments, but case to case transmission is by far the commonest cause of outbreaks. Most water-borne pathogens can be transmitted by other vehicles and few are characterised by poor case to case transmission. The exceptions are *Legionella pneumophila* and *Vibrio cholerae. Campylobacter spp.* are of interest because of the negligible case to case transmission, but the commonest species infecting humans, *C. jejuni and C. coli*, inhabit the intestinal tracts of wild birds and domestic animals: poultry are readily colonised and most broiler chickens sold in shops are contaminated.

Seasonal variation in water-related disease

The existing evidence shows seasonal variation in levels of water-related pathogens and increases that may relate to warmer summer temperatures. While suggestive of a link to climate change, there is little or no evidence, as yet, in the UK that the climate changes so far observed have affected water-related pathogens. This is partly because of the generally good quality of our water supplies and the precautions taken by water providers when breaches occur in water supplies. Water treatment has removed traditional water-borne pathogens, such as *Vibrio cholerae* and *Salmonella typhi*, from British water supplies and the very low frequency of these infections in the population ensures that treatment failures carry a negligible risk of contamination by these pathogens. i.e., the risk of water becoming contaminated is very low. The global increase in cholera has, however, been linked to the El Niño oscillation and other climate influences such as enhanced survival in warmer temperatures[9], but poor sanitation remains the most obvious underlying cause of human epidemics. *Cryptosporidium parvum* oocysts have proved able to penetrate water treatment in the UK, USA and other developed countries, but the incidence of cryptosporidiosis, although seasonal, relates also to practices in animal husbandry. *Campylobacter spp.* seasonality has attracted interest in a possible association with climate. Time trends have demonstrated seasonality in several countries, but although the seasonal pattern is more pronounced in Northern European countries, no correlation has yet been found with latitude of country and the month of seasonal peak of *Campylobacter spp.* reports. Campylobacter is now the commonest cause of bacterial gastrointestinal infection in the UK: while typing systems exist, these are not yet sufficiently developed to distinguish different epidemiological effects. Thus the influence of other vehicles, such as poultry and other foods, cannot be excluded from the data to allow analysis of the possible association between water-borne infection and climatic variables.

The evidence available from the investigation of water borne outbreaks of disease does not demonstrate any clear association with climate. Recent outbreaks in the UK have been predominated by *Cryptosporidium parvum*, with a possible trend towards more outbreaks associated with swimming pools and private supplies. The emergence of *Escherichia coli O157* as a cause of outbreaks linked to small private water supplies indicates the wider distribution of this pathogen in animal populations, but numbers are still low and there is no indication of a climate effect.

In summary, the evidence of seasonal variation is of interest to climate studies, but climate is likely to prove only one of the factors influencing the current trends in these pathogens.

If studies show a convincing link with temperature or precipitation variation, the next task will be to tease out all the other confounding factors and develop models of the potential contribution of climate alone. While the lack of information and evidence is to some extent reassuring, there would appear to be no room for complacency. Many of the more recently identified infections are water-related (*Cryptosporidium spp., Campylobacter spp., Legionella spp., Microspora spp.*). This suggests both that we have not had time to observe trends, and also that more organisms may emerge as the climate effects increase.

Potential effects of climate on water-related disease

The potential effects may include:

- ❑ changes in vector breeding patterns, e.g. mosquitoes;
- ❑ increased pathogen survival in natural waters e.g. *Vibrio cholerae;*
- ❑ decreased quality of drinking water;
- ❑ indirect effects due to increased exposure to water used in air conditioning e.g. *Legionella pneumophila;*
- ❑ algal blooms;
- ❑ increased leisure exposure to freshwaters and sea water;
- ❑ effect of extreme weather events such as floods: increased risk of pathogens breaching the water treatment and sanitation safeguards; and
- ❑ increased exposure to water-related pathogens in other countries during travel from the UK.

Concern about the sustainability and safety of water supplies in Europe is beginning to change the relative neglect of water as a source of disease. Water shortage and poor water quality remain a central concern in developing countries and are estimated to cause the deaths of 1.5 million children annually. Concern about the importation of water-related disease is also rising: the concerns relate both to travel associated disease in visitors to countries with poor water control and sanitation and also to foods contaminated by unwholesome water. Recent initiatives with relevance to water surveillance include the proposed European Community Water Framework Directive, with particular reference to sustainable water use and mitigation of the effects of floods and droughts. The European Water Protocol drawn up by the WHO and UNECE (UN Economic Commission for Europe) places a greater emphasis on the health impact of water and the implications for surveillance, indicators of pollution and early warning systems.

Blue green algae

Climate change may increase the incidence of problems related to blue green algae (cyanobacteria), of which swimmer's itch is one of the less severe, but irritating, effects[10]. Skin reactions are the most commonly reported effect in the UK. Contact with cyanobacteria has also been associated with rhinitis, gastrointestinal complaints and atypical pneumonia[11]. Some algal toxins have tumour-enhancing properties, suggesting the possibility of disease developing years after exposure, or after prolonged exposure to relatively small doses of toxin. Little epidemiological research has been done on the risk to human health from freshwater or coastal algal blooms.

While temperature is an important factor, the observed increase in freshwater toxic algal blooms in recent years may be related to changes in agricultural run-off or to reduced river flow and associated increases in nutrient load. Increases in freshwater algae blooms have been observed in unusually hot summers in the UK[12,13]. The major bloom-forming species produce potent toxins, including hepatotoxins and neurotoxins[14]. However, there is little correlation between the composition of a particular bloom and the concentration of toxin present. Blooms cause serious water pollution problems, requiring the use of alternative water sources and closure of waters used for recreational and leisure activities. For example, during August and September 1989, substantial growths of blue green algae were observed in UK inland waters. The most publicised was at

Rutland Water in Rutland (Anglia Water), because of a putative association with the death of 20 sheep and 15 dogs which had contact with the water. However, no human health effects were reported, despite a wide range of recreational water sports and activities at Rutland Water. Anglia Water excluded their reservoirs from recreational purposes for a six-week period[15]. Later that summer, hospital treatment was required for two soldiers exposed to water during a canoeing course in Staffordshire: the illnesses developed one day after the course and included abdominal pain, vomiting, diarrhoea, skin blistering and atypical pneumonia[16]. The illness was attributed to ingestion and/or inhalation of toxic blue-green algae.

In coastal waters, the main risk from algal blooms is through contamination of shellfish. In the UK, dinoflagellates have caused sporadic cases of paralytic shellfish poisoning (PSP) in spring, along the north east coast of England and north and west coast of Scotland[17]. Problems with toxic dinoflagellates have also been associated in summer months with coastal waters of France and Spain. During the summer of 1999, the scallop fishery along the west coast of Scotland was closed because of the risk of amnesic shellfish poisoning (ASP). There is no evidence that coastal algal blooms have been affected by observed climate change.

Sewage in coastal waters

It is UK policy that all significant discharges of sewage are treated to at least secondary level whether the discharge is to inland surface water, groundwater, estuaries or coastal waters. Some discharges which impact on bathing waters or shellfish waters can receive even higher levels of treatment such as UV disinfection or microfiltration. The dumping of sewage sludge to sea was banned from the end of 1998. The treatment of sewage significantly reduces, but does not eliminate, the potential for pathogens to be discharged into the aquatic environment and studies have shown a small but significant risk of minor infection following exposure to seawater contaminated by sewage[18,19]. Climate change may alter the effect of such exposures, for example, warmer waters will reduce the survival of sewage-derived pathogens but the frequency and duration of exposure may be increased by warmer spring, summer and autumn weather.

The health implications of droughts and floods

The health implications of droughts and of floods vary greatly with location and circumstances. In the UK there is no evidence to suggest significant health problems arising from either drought or floods in recent years. This absence of health effects may be related to a number of factors and not least to a well developed water and sanitation system and an informed public. However, water availability has indirect influence on disease via hygiene and floods elsewhere in the world with an increased spread of cholera, leptospirosis and infections associated with rodents[20].

Droughts have a gradual onset and can occur anywhere, a critical factor being water usage. Droughts may kill due to a lack of water for drinking and can lead to forced migration and complex emergencies. Vulnerability to drought comprises a mix of social and political factors and, in terms of global change, climate change is but one factor to consider amongst many others, such as population growth.

The monitoring of drought and seasonal forecasting in many parts of the world provide forewarning for drought management. Unlike many climatic and natural hazards, there should be adequate time to implement, but not necessarily to plan, mitigation responses. Drought has profound socio-political effects which extend beyond the issue of water management. In drought-affected countries, the assessment of social vulnerability has matured, with new operational schemes and vulnerability mapping are used to target food aid and development assistance. In the UK, government institutions need to plan to adapt to water shortages through a variety of social and individual behaviour measures. Future patterns of individual usage of water may have health consequences, for example if water is metered and costed accordingly.

In the UK we already have droughts and hose-pipe bans in the summer season. According to the meteorological models, climate change could result in a substantial increase in winter precipitation, but evaporation will also increase. The result could be more frequent water balance deficits in the summer months. Precise impacts of changing rainfall and evaporation are of current concern to hydrologists, agriculture and water management, as water companies are undertaking aquifer modelling, studies of future reservoir levels, etc. Drought management is not a simple matter of the availability of water supplies, but involves understanding and controlling patterns of usage. A very detailed piece of work will be needed to explore these patterns and the appropriate adaptive measures required at a political and social level. A large number of pressures are already putting extensive demands on water usage, with climate effects forming just one aspect of an existing and complex problem. Health issues surrounding water shortages are therefore already with us but work in this area on health consequences should take into account the measures being introduced and planned under current water management.

Water infection problems associated with drought in the UK

The last significant drought period occurred in the early 1990s. Two cryptosporidiosis outbreaks in this period were attributed, in part, to changes in water management prompted by the need for alternative or additional water supplies. One occurred in the north east[21], where the predominantly bore-hole supply was supplemented during periods of high demand by water abstracted from a river. The other outbreak occurred on the south east coast, also associated with augmentation of a water supply during a drought period[22]. Yorkshire experienced a drought in the summer of 1995, despite normal rainfall in the previous winter[23]. Formal restrictions on water use were introduced, in addition to a large-scale tankering operation. The surveillance issues included assessing the risk of water-washed disease, that is, disease controlled by adequate washing (see above). However, the public health issues were dominated not by infection, but by the largely uncooperative public reaction to the crisis[24-28].

Water infection problems associated with floods in the UK

Studies have not shown a convincing increase in infection associated with flooding in the UK. There was no evidence of increased level of cases of leptospirosis, nor of serological evidence of exposure, after floods in Herefordshire (1997/1998) (Dr Coleman, Director Hereford PHL, *pers comm*). A detailed study was attempted after widespread flooding in North Wales in February 1990, due a storm induced surge[29]. More than 750 properties and numerous caravans were damaged. The infections observed were minor, such as slight increases in dysentery and rotavirus infections. Of greater health significance was the effect of cold, psychological shock and displacement, particularly as a third of the local population was aged over 60 years.

Implications for climate-related surveillance of water-related disease

More comprehensive surveillance in Europe of organisms related to water and of travel related disease is needed. This is unlikely to develop without specific funding and defined targets. Risk assessment is beginning to be applied to water supplies in much the same way that the HACCP (Hazard Analysis Critical Control Point) system has been applied to food preparation. The difficulties in identifying water as a cause of disease have delayed the development of scientifically satisfactory risk assessment systems for water-related infections. One possibility is the analysis of outbreaks: these provide the opportunity to document the events and errors preceding an outbreak and to identify control points. Incidents of water treatment failure, burst mains or floods could also be examined from the risk perspective in terms of the investigations required to ascertain any health effects and the differences between incidents leading to outbreaks and those in which no increase in disease is identified in the community. Another under-researched topic in risk assessment is the influence of human behaviour, for example the variation in water consumption associated with travel away from home and perceived environmental risk. Little is documented about variation in water habits between different ages, classes or occupational groups.

Key areas include more comprehensive and detailed active surveillance of reported outbreaks and incidents; development of a database on incidents of reported water failure and linkage to any reported cases of infection; climate change surveillance, including linkage of water-related disease reports and reports of increase in organisms with a strong water aetiology, to meteorological data. Surveillance should also include the follow up of floods, droughts and other adverse weather events. There is a trend towards using small area statistics and postcode analysis to identify clusters and regional concentrations of disease possibly attributable to water, although this involves as yet unresolved issues of both confidentiality and resources.

Data available for analysis

Data-sets have been obtained from CDSC which could be used for analysis of the effects of climate change on water-borne or water-related diseases. These include weekly reports of *Campylobacter spp.* and *Cryptosporidium spp*. over the last decade. To make appropriate use of these data it will be necessary to subdivide according to known or suspected aetiology, including travel exposure. As the laboratory reports are used primarily to assist with clinical management and in the control of acute outbreaks, there may also be confidentiality and access limitations in the light of new guidelines on data use. For many reports, the data set is limited to clinically relevant information such as date of isolate, age of the patient and in some cases to the severity of infection. However, such data would be a good starting point and would allow examination of crude trends and links with different lag periods following temperature or rainfall peaks.

4.4.3 Research needs

- An investigation of variation of *Campylobacter spp.*, *Giardia spp.* and *Cryptosporidium spp.* with temperature and precipitation data, including analysis of different lag periods between peak temperatures and rainfall with date of onset of isolation of increased number of bacteria is needed. Data on infections need to be supplemented with information on travel exposure and to be subdivided by other possible or confirmed aetiologies, e.g. case to case transmission, foodborne disease and water treatment failures unrelated to extreme weather events. Because of the need for large data sets, covering extremes of temperature and precipitation, there is also a strong case for sharing data across the European region.
- A review of studies on the health effects of recreational exposure to inland and marine waters, with associated analysis of water quality and seasonal/climate variation is needed.
- Risk and public health intervention analyses based on predicted changes, associated with behavioural studies and likely impact of public health interventions such as health warnings about bathing, water consumption, travel related behaviour etc are needed.

4.4.4 References

1. Kay D, MacDonald AT. Reduction of coliform bacteria in two upland reservoirs: the significance of distance decay relationships. Water Res 1980; 14:305-318.

2. WHO. Guidelines for drinking water quality, 2nd edition: Volume 3. Surveillance and control of community supplies. Geneva: World Health Organization, 1997.

3. Department of the Environment, Department of Health. Third report from the Group of Experts on Cryptosporidium in Water Supplies (Bouchier Report). London: HMSO, 1998.

4. Galbraith NS, Barrett NJ, Stanwell-Smith R. Water and disease after Croydon: a review of water-borne and water-associated disease in the UK 1937-86. J Inst Water Environ Manage 1987; 1:7-21.

5. Stanwell-Smith R. Water and public health in the United Kingdom: recent trends in the epidemiology of water-borne disease. In: Golding AMB, Noah N, Stanwell-Smith R, editors. Water and public health. London: Smith-Gordon & Co, 1994.

6. Bradford Hill A. The environment and disease: association or causation? Proc Roy Soc Med 1965; 58:295-300.

7. Communicable Disease Surveillance Centre. Strength of association between human illness and water: revised definitions for use in outbreak investigation. Communicable Dis Weekly 1996; 6:65.

8. Hunter P. Waterborne disease: epidemiology and ecology. In: Drinking water and waterborne disease. Chichester: John Wiley & Sons, 1997.

9. Colwell RR. Global climate and infectious disease: the cholera paradigm. Science 1996; 274:2025-2031.

10. Eastcott HR. Swimmer's itch: a surfacing problem? Communicable Dis Rep 1988; 88:3-4.

11. Elder GH, Hunter PR, Codd GA. Hazardous freshwater cyanobacteria (blue green algae). Lancet 1997; 341:1519-1520.

12. George DC, Emmett BA, Reynolds B. Impacts on freshwater ecosystems. In: Impacts of mild winters and hot summers in the United Kingdom 1988-90 London: HMSO, 1997.

13. Palutikof JP, Subak S, Agnew MD editors. Economic impacts of the hot summer and unusually warm year of 1995. Report for the Department of the Environment. Norwich: University of East Anglia, 1997.

14. Codd GA, Roberts C, editors. Public health aspects of cyanobacteria (blue-green algae). PHLS Microbiology Digest, 1991; 8:78-100.

15. NRA. Toxic blue-green algae. NRA Water Quality Series No. 2. London, HMSO, 1990.

16. Turner PC, Gamme AJ, Hollinrake K, Codd GA. Pneumonia associated with contact with cyanobacteria. BMJ 1990; 300:1440-1441.

17. Joint I, Lewis J, Aiken J, Proctor R, Moore G, Higman W, Donald M. Interannual variability of PSP outbreaks on the north east coast. J Plankton Res. 1997; 19:937-956

18. Haile RW, Witte JS, Gold M, Cressey R, McGee C, Millikan RC, Glasser A, Harawa N, Ervin C, Harmon P, Harper J, Dermand J, Alamillo J, Barrett K, Nides M, Wang GY. The health effects of swimming in ocean water contaminated by storm drain runoff. Epidemiology 1999; 10:355-364.

19. Downing T. From a talk given by Dr Tom Downing, the Environmental Change Unit, University of Oxford, at a conference at The Royal Society entitled Dealing with Natural Disasters (27-20 October 1999) (reported by Dr P Baxter), 1999.

20. Colwell RR, Patz JA. Climate, infectious disease and health: an interdisciplinary perspective. Based on colloquium held June 1997 by American Academy of Microbiology in Jamaica. Washington: American Academy of Microbiology, 1998.

21. Aston R, Mawer SL, Casemore DP. Report of an outbreak of Cryptosporidiosis in North Humberside. PHLS Communicable Diseases Surveillance Centre, London, 1991 (unpublished outbreak report).

22. Joseph C, Hamilton G, O'Connor M, Stanwell-Smith R, Sims R, Ndawula E, Caremore D, Gallagher P, Harnett P. Cryptosporidiosis in the Isle of Thanet: an outbreak associated with local drinking water. Epidemiol Infect 1991; 107:509-519.

23. Barnes H. The Yorkshire drought, 1995. Abstract from talk given at CDSC annual conference on the epidemiology and control of infectious diseases and environmental hazards. CDSC Collindale November 2-6 1998. London: PHLS Communicable Diseases Surveillance Centre, 1998.

24. Rofe BH, Hampson E. Yorkshire Water Drought Orders 1995: Independent Assessment Report. London*: Department of the Environment.

25. Rofe BH, Hampson E. Yorkshire Water Drought Orders 1995: Second Assessment Report. London*: Department of the Environment,

26. Nixon JS. Yorkshire Water Services Ltd: Application for Emergency Drought Orders: Report of Public Hearings 14-17 November 1995. Yorkshire Water*

27. Water Supply in Yorkshire: Report of an Independent Commission of an Enquiry. Chairman Uff J. 1996*.

28. Yorkshire Water. Rota Cuts: Advice to Customers. Yorkshire Water*, 1995.

29. Englefield GJH, Tooley MJ, Zong Y. An Assessment of the Clwyd Coastal Lowlands After the Floods of February 1990. Durham: Environmental Research Centre, University of Durham, 1990.

* Cited by Barnes 1998. None of these have been formally published and referenced, but access is available via the Drinking Water Inspectorate, DETR, Yorkshire Water, the CCDC for Calderdale and Kirklees HA and the PHLS CDSC.

Further reading

Abrahams MJ, Price J, Whitlock FA, Williams G. The Brisbane floods, January 1974; Their impact on health. Medical Journal of Australia, 1976; 2: 936-939.

Bennet G. Bristol floods 1968. Controlled survey of effects on health of a local community disaster. British Medical Journal 1970; 3: 454-458.

Communicable Disease Surveillance Centre. CDR report July 1998/ Jan 1999/ July 1999.

Craun GF. Waterborne disease outbreaks in the United States of America: causes and prevention. World Health Statistics Quarterly, 1992; 45:192-199.

Dufour AP. Diseases caused by water contact. In: Water-borne diseases in the United States. GG Craun (ed). CRC Press, pp 23-41, 1986.

Kramer MD, Herwaldt BL, Craun GF, Calderon RL, and Juranek DD. Surveillance for waterborne-disease outbreaks - United States, 1993-1994. Morbidity and Mortality Weekly Report 1996, 45 (SS-1):1-33.

MacKenzie WR, Hoxie NJ, Proctor ME, Gradus MS, Blair KA, Peterson DE, Kazmierczak JJ, Addiss DG, Fox KR, Rose JB, Davis JP. A massive outbreak in Milwaukee of cryptosporidium infection transmitted through the public water supply. New England Journal of Medicine, 1994; 331: 161-167

Moore AC, Herwaldt BL, Craun GF, Calderon RL, Highsmith AK, and Juranek DD. Surveillance for waterborne disease outbreaks - United States, 1991-1992. Morbidity and Mortality Weekly Report 1993, 42 (SS-5):1-22.

Stanwell-Smith R, O'Brien S. Cholera in tourists returning from Kenya. Eurobulletin 1998;2:416

(http: //www.eurosurv.org)

Stanwell-Smith R. Water-related surveillance in Europe. Eurosurveillance Weekly 1999;3:990304 (http://www.eurosurv.org)