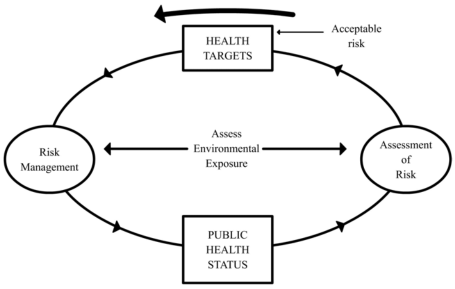

11

A public health perspective for establishing water-related guidelines and standards

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For a number of historic reasons, the setting of water-related guidelines has become fragmented among different agencies and divorced from general public health. This runs contrary to the fundamental public health perspective that views the control of pathogens (including waterborne ones) as a more holistic activity, integrating across all exposure pathways. There are two levels at which this integration occurs. At one level, the focus is on proximal factors, such as water quality, sanitation and hygiene that have a direct causal link to disease as depicted through a 'systems' approach to transmission cycles. At another level the focus is on the distal causal factors, such as socio-economic conditions, which have an impact both on the health of a society and on individuals through their linkages to the proximal factors. The purpose of this chapter is to provide a

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public health perspective to motivate the need for an integrated approach to guidelines setting and, in keeping with the public health tradition, it draws together a number of 'threads' presented in earlier chapters.

This chapter, alongside Chapter 10 on acceptable risk, is especially relevant to developing understanding and approaches to the formulation of national/local objectives in terms of negotiated and agreed health targets that can be converted into implementable regulations.

11.1 INTRODUCTION

Public health has been defined as 'the science and art of preventing disease, prolonging life and promoting health through organised efforts of society'. It is concerned primarily with health and disease in populations, complementing, for example, medical and nursing concerns for the health of individual patients. Its chief responsibilities are monitoring the health of a population, the identification of its health needs, the fostering of policies that promote health, and the evaluation of health services (i.e. not only health-care services, but the totality of activities undertaken with the prime objective of protecting and improving health).

Modern public health can be traced back to the mid-nineteenth century and the work of two different men; John Snow and Edwin Chadwick. John Snow is credited as being the first person to use epidemiological methods to investigate an outbreak of cholera in the East End of London. This investigation enabled him to identify water from a single pump as the cause of the outbreak and to implement an effective control measure, namely removing the handle from the pump. Edwin Chadwick wrote *Report on an Inquiry into the Sanitary Condition of the Labouring Population of Great Britain*, one of the most important documents in the history of public health. In it, he argued that the economic cost to society of disease due to poverty, overcrowding, inadequate waste disposal and nutrition was unacceptable and greater than the cost of trying to improve these conditions. These two aspects of public health (epidemiological investigation of disease leading to effective intervention and concern with influencing social policy to improve health) emphasise that there exist distinct environmental components that impact on disease transmission. In one, the association of disease with a particular environmental source was sufficient to dictate an intervention. In the second example, Chadwick focused on the importance of social factors and therefore saw socio-political reform (such as reform of the poor law) as the major intervention in reducing disease and improving health.

As Chadwick argues, there is a wide array of social (or distal) factors in addition to biological (or proximal) factors that determine the impact of a particular pathogen on health and also the relative importance of the various transmission pathways that contribute to the disease burden. Therefore, although the proximal factors that describe the transmission cycle may be the direct cause of disease, they are often mediated by the distal factors. It is the role of public health to understand the relationship between the distal causalities (often associated with socio-economic status) and the proximal causalities (associated with biologic factors) and how these will inform intervention and control. This public health role is one that applies generally across all disease processes.

One basic feature of waterborne pathogens that makes them unique is the ability to survive in the environment outside of a host. This is a principal factor that largely dictates the possible transmission pathways that can be exploited by a waterborne pathogen in completing its lifecycle, and has implications for intervention and control. In addition to clinical controls, such as vaccination or chemotherapy, there are also a number of possible environmental controls. These include the treatment of water or other environmental media, limiting exposure to water or other environmental media, and prevention of contamination through sanitation and hygiene measures. Each of these strategies may not only reduce the disease burden associated with its pathway, it may also reduce transmission from other pathways by decreasing the amount of contamination. This interdependency of pathways suggest that to determine the most effective control requires an understanding of the complete transmission cycle. The relationship between proximal and distal factors, however, suggests that an integrated public health perspective for water-related activities should account not only for the disease transmission perspective addressing the proximal causalities, but also the distal causalities that may impact on those proximal factors.

A suitable metaphor for public health is a thermostat for the health of society. A thermostat is a negative feedback loop; one for room temperature has three components, namely:

- A sensor to measure the temperature within the room.
- A comparator to compare the room temperature with a pre-set ideal temperature.
- An actuator designed to control the flow of hot water to the radiator.

These components in public health are classed as:

- Surveillance to measure risk.
- The comparison of measured risk and predefined acceptable risk resulting in a decision on control strategies.
- Public health interventions.

'Surveillance' in this model covers the application of epidemiological tools in a descriptive manner to monitor disease incidence and in an analytic manner to assess the association of risk factors with disease incidence (see Chapters 6 and 7). Such tools may be used to investigate endemic disease in a community or outbreaks of disease as and when they occur. The comparison and subsequent decision requires a model. In public health the model is often conceptual and not necessarily explicit. Disease transmission systems, however, have been represented in the past as a mathematical model to compare data supplied by surveillance and acceptable risk values (issues on acceptable risk are covered in more detail in Chapter 10). It has also been used to provide an optimal control strategy that can then be implemented through public health intervention. Surveillance activities have little value unless they have the potential to lead to improved public health and safety by public health interventions. These interventions may be specific and small scale (removing the pump handle) or more general (development of national/international policies and strategies). Surveillance activities then come into play once more as the impact of any health intervention is evaluated.

11.2 A PUBLIC HEALTH PERSPECTIVE ON THE NATURE AND DETERMINANTS OF DISEASE

In this section we first discuss the nature of disease from a public health perspective and then go on to discuss some of the determinants of ill health.

11.2.1 Nature of disease

11.2.1.1 Health and disease

The World Health Organization (WHO) has defined health as a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity. This definition is extremely valuable. Of necessity, many of the chapters in this book concentrate on infectious disease and neglect the more holistic view of health. However, without an understanding of the impact of our efforts on health as well as on disease we may risk reducing the potential benefit of our interventions. People's quality of life is better when they have access to an adequate supply of water. If women do not have to walk many miles a day just to collect water they have more time for themselves and their families. Water also has a symbolic or spiritual meaning in many societies and the availability of water around the home adds to the sense of well-being. These and related issues are difficult to include in any formal epidemiological or risk assessment framework, but have powerful influences on health.

Turning to the nature of disease, there are several ways that disease can be categorised:

- According to the underlying aetiology (e.g. genetic, infectious, environmental, nutritional, etc.).
- According to the main disease process (e.g. inflammatory, malignant, degenerative, etc.).
- According to the main body system affected (e.g. respiratory disease, neurological disease, etc.).
- According to the course the disease follows and subsequent outcome (e.g. an acute course with recovery, acute course with death as the outcome, a chronic course etc.).

Which classification system is used depends on the purpose of the classification. Here we are primarily concerned with infectious disease spread by water. The outcomes and impacts of waterborne diseases can be acute, chronic or delayed. The distinction of these outcomes has public health importance. The effects of acute diseases occur over a short period of time whereas the effects of chronic diseases accumulate over much longer periods of time. Comparing the health of an acute versus a chronic disease can be done using Disability Adjusted Life Years (DALYs) (see Chapter 3).

As with other diseases, water-related diseases may be classified in a variety of ways, for example, according to the nature of the causative agent (protozoan, bacteria, virus etc.), or by the nature of the disease produced (diarrhoea, dysentery, typhoid, hepatitis and so on). With respect to intervention and control, however, a more appropriate classification is one based upon how changes in (largely environmental) conditions could impact on disease transmission. As such it represents a broad categorisation of principal environmental pathways.

11.2.1.2 Routes of transmission

Infectious agents have a number of options for their transmission. In general these are:

- Direct person-to-person transmission through intimate contact (such as sexually transmitted diseases).
- Direct person-to-person spread through infected body fluids (such as blood-borne viruses).
- Direct person-to-person spread through less intimate contact (such as influenza or viral gastroenteritis).

- Spread via contamination of the environment, which may include contamination of inanimate objects (fomites), water or air.
- Spread via contaminated food (such as *Salmonella*).
- Spread through an insect vector (such as malaria).
- Spread from a primary animal host to humans, either directly or indirectly via food or a contaminated environment.
- Spread to humans by environmental organisms (such as *Legionella*).

Pathogens are often able to use many of these pathways. For example, Norwalk-like viruses can be spread from person to person directly, via contaminated food, drinking water or fomites. Table 11.1 lists a classification of water-related diseases.

Table 11.1. Classification of water-related disease (after Bradley, 1974)

Category	Comments
Water-borne diseases	Caused by the ingestion of water contaminated by human or animal faeces or urine containing pathogenic bacteria or viruses; includes cholera, typhoid, amoebic and bacillary dysentery and other diarrhoeal diseases.
Water-washed diseases	Caused by poor personal hygiene; includes scabies, trachoma and flea-, lice- and tick-borne diseases in addition to the majority of waterborne diseases, which are also water-washed.
Water-based diseases	Caused by parasites found in intermediate organisms living in water; includes dracunculiasis, schistosomiasis and some other helminths.
Water-related diseases	Transmitted by insect vectors which breed in water; includes dengue, filariasis, malaria, onchocerciasis, trypanosomiasis and yellow fever.

We may wish to add to this list a fifth category, that of water-collection-related disease. This would include those diseases where spread is aided by journeying to collect water, as was found to be the case in an outbreak of meningococcal disease in a refugee camp (Santaniello-Newton and Hunter 2000). In addition, some pathogens do not infect sites within the human body but act remotely by the production of toxins that are subsequently ingested. The best water-related example of this mode of action is provided by the toxic cyanobacteria (Chorus and Bartram 1999). The role of the toxins produced by these organisms in their ecology is poorly understood. They represent a potential sixth category of water-related disease, associated with water contact.

All of the potentially waterborne pathogens share the ability for at least one of their life stages to survive, to a greater or lesser extent, outside the (human) host. The extent of that survival varies widely from presumably very short (e.g. *Helicobacter pylori*) to many years under favourable circumstances. Survival may be purely passive (many viruses), may involve robust life stages (such as the cysts and oocysts of *Giardia* and *Cryptosporidium* respectively) or may involve specific associations (such as that of *Legionella* with some free-living protozoa or *Vibrio cholerae* with certain cyanobacteria). This environmental survival distinguishes waterborne pathogens from others associated with, for example, transmission via the respiratory route (such as measles) that must infect a susceptible human host soon after leaving an infectious host.

In contrast to the situation with non-infectious disease, the risk of infection and illness is related to the level of microbial pathogens in the environment. For exclusively human pathogens, the degree of environmental contamination is related to the number of infected people. The more people with rotavirus in a community, the more likely an uninfected individual will catch it. This is because the source of all pathogens ultimately becomes the infected hosts. For many infectious diseases, the pathogen reproduces within the human host, who therefore acts as an amplifier. In order for a pathogen to persist, it must reproduce in sufficient numbers within a given host in order to allow for the infection of another host.

The specific journey a pathogen takes from host to host defines the transmission pathway and this may include non-human hosts. Diseases that are maintained within an animal population and sporadically introduced to human hosts are referred to as enzootic (c.f. endemic – upon people). For environmentally mediated pathogens, these pathways are often characterised by a significant time period outside the host. Humans can become infected through ingestion, inhalation, or dermal contact of/with pathogens.

The degree of contamination, and therefore the degree of risk, depends on the contributions of all of the different environmental transmission pathways. The transmission pathways increase in complexity when there are animal hosts that a pathogen can infect. Examples might include non-typhi *Salmonella*, *E. coli* and the bovine species of *Cryptosporidium*.

With respect to pathogen transmission, the number of cases or symptomatic individuals is not the only issue. It is also possible for an individual to be infectious but not symptomatic. These asymptomatic individuals are usually mobile due to lack of illness and have a high potential to spread a pathogen widely throughout a community.

Specific circumstances vary widely and, according to local conditions, any given pathway may dominate or make a negligible contribution to overall disease causation. Because of the importance of specific local circumstances, the relative contribution of different pathways cannot be properly/comprehensively taken into account in the development of international norms such as WHO guidelines. The development of an understanding of local conditions and their impact on disease transmission pathways is an essential/very desirable step in adapting international guidelines to national standards (this is also an essential component of HACCP which is a generic risk-based system – see Chapter 12). A logical consequence is that national standards will progressively evolve in response to their own implementation and success. Thus, as a dominant route of exposure is partially or entirely controlled, so other routes will become of greater relative importance. If the remaining disease burden is judged to merit public health action then these routes will then become the focus of national and local regulatory activity.

11.2.1.3 Endemic disease, epidemic disease and outbreaks

Whilst the terms endemic, epidemic and outbreak may be used loosely and interchangeably in common parlance, these terms have precise meanings within the discipline of public health.

When a pathogen transmission cycle is at equilibrium within the human population the disease incidence is referred to as the endemic level, and the number of new cases remains approximately constant. An outbreak or epidemic is defined as a significant increase in the number of cases in a population over a given period of time. The term 'epidemic' is usually used for general increases in a population such as occurs with influenza (and can occur over long periods of time such as with AIDS). In contrast, the term 'outbreak' is usually used for a localised increase that occurs over a short period of time (a month or less). There are different types of outbreaks:

- point source outbreaks, in which all cases are infected at the same time;
- continual source outbreaks, in which all cases are infected over time from a source that is continually or sporadically infectious;
- propagated outbreaks, in which the disease is spread by person-to-person transmission; and
- mixed point source and propagated outbreaks, in which a point source is responsible for initial cases but then the disease is propagated to secondary cases through person-to-person spread.

Outbreaks, as compared with the endemic situation, present a large number of cases in a short period of time. Environmental health measures to control outbreaks may be very different from those intended to reduce the background (endemic) rate of disease.

As is outlined in some detail in Chapter 6, with many water-related diseases real problems are encountered in both detecting and estimating the magnitude of outbreaks and in quantifying the contribution of water to the overall disease burden.

It is generally accepted that outbreak events have special importance in public health and this should be accounted for in establishing health targets and from them, for example, water quality objectives. Thus, for example, while a public health target may be expressed in terms of a maximum tolerable disease burden, this may not be considered acceptable if it were to occur as the result of a single event. Public health target-setting may therefore make separate reference to outbreaks. Once converted to water quality objectives, this implies the need to pay special attention to extreme events (even if rare) in addition to steady-state conditions and performance.

11.2.2 Determinants of ill health

Disease is not evenly spread through society, and one of the important roles of public health is to identify the causes of this uneven distribution so that strategies can be developed to reduce risk and improve health. There are a large number of determinants of ill health. This chapter will outline four that have a significant impact on the water-related disease.

11.2.2.1 Environmental exposure

We have already discussed at length the impact of different transmission pathways (both water and non-water) on the epidemiology of waterborne disease. Clearly for any particular route of transmission to effectively transmit infection, susceptible individuals need to come into contact with the particular environmental source. The degree of such exposure is a major factor in the differential risk between individuals in a community.

For example, the amount of tap water consumed each day varies substantially from one individual to another, as does the amount of time a given individual swims. This variation in exposure has a substantial impact on the risk of infection (Hunter 2001). In a recent outbreak investigation, people who regularly went swimming were at lower risk during a drinking waterborne outbreak of cryptosporidiosis, presumably due to immunity after prior infection (Hunter and Quigley 1998). Of increasing concern, at least in developed countries, is the issue of travel-related disease (see Chapter 4), where travellers may find themselves exposed to environmental pathogens to which they have had no previous exposure.

11.2.2.2 Pre-existing health

Another important factor in the variation in ability to deal with infectious agents is an individual's existing state of health. The classic example of this is the severity of cryptosporidiosis in patients with AIDS (in whom infection may be fatal, whereas it is typically relatively mild in immunocompetent individuals). Other diseases that may affect an individual's response to a waterborne pathogen include diabetes mellitus (Trevino-Perez *et al*. 1995), malignant disease (Gentile *et al*. 1991) and organ transplantation (Campos *et al*. 2000). Perhaps the greatest impact on risk from waterborne disease worldwide is the impact on heath from malnutrition (Griffiths 1998).

11.2.2.3 Poverty

Most public health practitioners would accept that the biggest impact on human health and disease risk comes not from specific environmental factors or routes of transmission but from the social conditions in which an individual lives. Undoubtedly, poverty (both absolute and relative) is the biggest threat to health of any identifiable risk factor (Bartley *et al*. 1998; Townsend *et al*. 1992; Wilkinson 1996). People subject to poverty are more likely to suffer disease due to increased exposure to pathogens from inadequate environmental controls. Furthermore, once affected by disease, they are likely to suffer more severely because of inadequate health-care and social support systems and from poorer general health due to malnutrition and behavioural factors (such as smoking).

11.2.2.4 Acquired immunity

One of the most fundamental features that distinguishes microbiological hazards from chemical hazards in relation to human health is the phenomenon of acquired immunity i.e. the protection conferred to a host after exposure to a pathogen. For some pathogens (such as hepatitis A) once a person has been infected they will never contract the illness again (i.e. the protection is lifelong). For most waterborne pathogens the protection conferred to a host after exposure to the agent of disease is partial and temporary. For example, an individual with protective immunity due to prior exposure may require a larger dose in order for infection to occur or for symptoms to develop. Such partial protection may last for months or years. This property of infectious disease has major implications with respect to transmission both within and between populations. The greater the number of partially protected individuals, the smaller the pool of susceptible individuals that are at risk. This in turn implies that there will be a smaller pool of newly infected individuals in the future. The decreased number of infected individuals in the future means that there will be less contamination, decreasing the exposure risk.

The second aspect of complexity concerns the situation where populations from areas of low endemicity (and therefore with low immunity) travel to areas of high endemicity and therefore higher risk. Such situations occur increasingly frequently with the increasing trend in international travel. The most conspicuous example concerns the hepatitis A virus. In industrially developed nations, hepatitis A is largely controlled through water supply, sanitation, food and personal hygiene to the extent that most individuals are not exposed to the virus at all during their lifetime. In contrast, in areas where low hygiene standards prevail, hepatitis A exposure tends to occur early in life and is a relatively benign infection. However, a first exposure to hepatitis A among adults leads to a far more severe disease course. The greatest importance of hepatitis A virus is therefore to susceptible adults travelling to areas of high endemicity. For some groups of such individuals (e.g. some tourists and international aid workers) vaccination is recommended.

11.3 SKILLS AND TOOLS USED BY PUBLIC HEALTH PRACTITIONERS

Many primary scientific approaches are available to the public health practitioner in order to investigate the causes, impact and control of disease in populations. The discipline most closely associated with public health is epidemiology. Other disciplines of value include mathematical modelling, biological and physical sciences, social sciences (including economics), and demographics and vital statistics (Detels and Breslow 1997). The task of providing the best scientific information required for policy-making is difficult, due largely to the fact that environmental processes governing human health risks are complex. No single discipline can provide the information necessary to make a scientifically sound decision. Such decision making, therefore, requires careful consideration of both the information each discipline provides and their limitations. In this section we will bring together issues brought up in Chapters 6, 7 and 8 (on surveillance, epidemiology, and risk assessment modelling) from a public health perspective. More detailed descriptions of these methodologies are discussed in the respective chapters.

11.3.1 Epidemiology

Epidemiologists may utilise a number of descriptive and analytical techniques that are all based on statistical inference as a basis of proof. Epidemiological proof is built up over time as the results of various studies are added together into a body of knowledge. One of the first people to lay down principles of epidemiological proof was Bradford-Hill (1965). He suggested nine criteria from which proof of a link between human disease and exposure to a potential risk factor could be derived:

(1) Strength of association, as measured by odds ratio, relative risk or statistical significance.
(2) Consistency of finding the same association in studies conducted by many different researchers.
(3) Specificity of association such that a particular type of exposure leads to a particular disease.
(4) Temporality, in that the exposure must precede the disease.
(5) Biological gradient: people with higher exposure should get more disease.
(6) Plausibility: the proposed causative pathway must be plausible.
(7) Coherence: the hypothesis must not conflict with what else is known about the biology of the disease
(8) Experiment: can the link be supported by experiment such as intervention studies?
(9) Analogy: is there another similar disease which has a similar link?

Outcome measures from epidemiology studies are used to estimate risk. In epidemiology, risk has the connotation of probability of illness. This is, in turn, related to how common a disease is in a community. There are two measures of the commonness of disease; incidence and prevalence. The incidence of a disease is the number of new cases occurring within a certain population during a specified time period (e.g. cases per 100,000 persons per year). Prevalence is the number of cases of a disease within a specified population at a specific point in time (e.g. cases per 100,000 persons).

There are three types of epidemiological risk. Absolute risk is, in effect, the incidence of disease that tells us little about the possible causes of a disease. Attributable risk is the proportion of cases of a disease that can be linked to a risk factor, usually given as a percentage. Relative risk is the ratio between the risk of disease in one population (exposed to a particular risk factor) and a second population (not exposed).

If we know the absolute risk and either the attributable or relative risk we should have sufficient information to judge the importance of a disease and the importance of various risk factors. Unfortunately, getting accurate information on risk is not necessarily that easy given, for example, limitations in obtaining estimates of absolute risk from surveillance systems, or estimates on both attributable and relative risks, from detailed analytical epidemiological studies. Even if we were able to obtain this information on relative risk, for example, it may not tell us the impact on human health of removing a particular risk factor. For example, if the attributable risk of infection due to drinking water contaminated with Norwalk-like virus (NLV) is 20%, removing drinking water as a source of infection would not necessarily reduce disease by 20%, as people may then be infected from other sources. On the other hand, disease reduction may be greater than 20% if this reduced the risk of secondary cases in a community.

This intervention example illustrates a very important property of infectious disease transmission processes; that transmission pathways are interdependent. The traditional definition of attributable risk is based on the assumption that risk at the individual level is an independent process (i.e. the probability of an individual becoming diseased is independent of the disease status of other individuals within the community). This assumption is violated for an infectious disease process since the source of pathogens is generally other infected hosts. For example, a pathogen present in the water may infect an individual that drinks the water. This individual may then directly transmit the pathogen to others within a household, some of whom may become asymptomatic carriers who in turn transmit pathogens to a recreational water area, exposing susceptible swimmers. Other infected individuals may contaminate the wastewater that will subsequently be used in an agricultural setting, resulting in an occupational exposure. This illustration of typical causal pathways makes it clear that it is difficult to assign any of these individual cases to a specific risk factor (i.e. should these cases be considered a drinking water risk or an occupational risk) and emphasises the need for a harmonisation process, whereby water-related areas are considered together rather than in isolation.

The critical feature of the transmission process that presents us with this issue of interdependence is the fact that these pathogens cycle from host to host. This interdependence of transmission pathways is the reason that the impact of a given intervention, as mentioned above for drinking-water treatment of NLV, is not simply the attributable risk. To empirically assess the effect of treating the drinking water on disease prevalence of NLV requires an intervention study. Disease transmission models, which explicitly account for this interdependence, can provide the theoretical framework from which to address these issues and can be useful in both the design and analysis phases of intervention studies.

11.3.1.1 Surveillance

Epidemiological surveillance is the ongoing and systematic collection, analysis and interpretation of health data in the process of describing and monitoring a health event. This information is used for planning, implementing and evaluating public health interventions and programs. Surveillance data are used both to determine the need for public health action and to assess the effectiveness of programs (Klaucke *et al*. 1988). Surveillance is discussed in more detail in Chapter 6.

The discussion here will be restricted to how surveillance systems can feed into national and international public health policy and standard setting. Surveillance systems are established for a number of different reasons:

- To identify outbreaks/adverse incidents early enough to implement possible control measures.
- To identify patterns of disease in order to identify risk factors so that control measures can be implemented or standards set.
- To evaluate the impact of prevention and control programmes.
- To project future health-care needs (i.e. all activities undertaken with the prime objective of protecting and improving health).

Because in this context we are primarily concerned with setting standards for waterborne disease, the primary functions of disease surveillance are:

- To establish the incidence and severity of disease so that priorities can be set.
- To attempt to identify the association between risk of disease and exposure to environmental exposure to water.
- To assist in identifying specific contributory factors to disease transmission and thereby inform risk management (see Chapter 12).

Unfortunately, existing surveillance systems cannot necessarily provide this information. Surveillance systems capture relatively few of the cases of illness occurring in a community and hence are poor indicators of disease burden. Additionally, detection rates for enteric disease can vary dramatically from one disease to another. For example, one UK study suggested that national surveillance systems would detect only 31.8% of *Salmonella* infections, 7.9% of *Campylobacter* infections, 3.0% of rotavirus infections and 0.06% of Norwalk-like virus infections (Wheeler *et al*. 1999).

Existing surveillance systems often have very limited information about possible risk factors and the lack of data on controls makes what information that is available difficult to interpret. Furthermore, data collected by surveillance systems may not be representative of the general level of disease in the community. Differential reporting between doctors and areas may bias results.

One area in which routine surveillance can provide good information is in detecting changes over time (although whether these changes are due to changing incidence or improved diagnosis is frequently unclear). One particular aspect in this regard is the detection of outbreaks (provided that they are large enough to be obvious against the general background incidence of a disease). Outbreaks can provide very useful information about possible risk factors (such as failures in water treatment or point source pollution), hence they have often been the driving force behind changes in standards and legislation. However, care must be exercised in extrapolating from knowledge about risk factors for outbreaks to endemic disease. Outbreaks are usually responsible for a relatively small proportion of total disease burden and the risks may differ.

11.3.1.2 Descriptive and analytical epidemiology

Chapter 7 is dedicated to a discussion of epidemiological techniques and so this will not be repeated here. What we will do is remind the reader that all epidemiological methods are potentially subject to problems from bias of one type or another (Greenland 1997; Hennekens and Buring 1987) and this can potentially reduce the value of epidemiology for policy makers. Two types of bias that can adversely affect the validity of epidemiological studies are selection bias and recall bias. To a greater or lesser extent these types of bias can affect any type of study if sufficient attention is not paid to them in the design stage.

Selection bias occurs when the selected study participants differ from the population from which they are selected. This can arise in a number of ways:

- If subjects are selected in a non-random fashion, by for example using volunteers or only cases presenting to hospital.
- If hard to contact subjects, such as those without a telephone, are excluded. In many societies, the poorest sections of society are not able to afford their own telephone.
- If response rate is low because a large proportion of subjects refuses to participate.

Recall bias can also arise in different ways:

- Cases may remember exposure to a potential risk factor differently from controls. So, for example, if it is believed that a waterborne outbreak is being investigated, cases may report higher water consumption than controls even if the reality is that no such difference exists.
- Subjects are more likely to state that they have suffered from particular symptoms if they believe that they are at increased risk of such symptoms.

This latter source of recall bias has been invoked recently in a renewed debate over the size of the Milwaukee outbreak of cryptosporidiosis. This outbreak is reported as being the world's largest documented outbreak of waterborne disease, affecting some 405,000 people (MacKenzie *et al*. 1994). This estimate, however, was based on a telephone survey conducted some time after the outbreak became big news in the city. Recently, Hunter and Syed (2000) conducted a similar study during a waterborne outbreak but included control towns that were close enough to the outbreak area for people not to be sure whether or not they were part of the outbreak. Surprisingly, they found that the incidence of self-reported diarrhoea was greater in the control areas than in the outbreak areas. They suggested this was due to recall bias following the intense media coverage.

11.3.1.3 Epidemiology and policy making

By collecting population-level health risk data, epidemiology provides information crucial to policy makers who set standards and guidelines. To make best use of these data, the relevance of each study, in the context of the policy decision, must be understood. Some of the issues that should be considered are the study design, confidence intervals of risk estimates, potential biases and generalisability (see section 11.4.2). Although no single study is expected to provide perfect information, interpretation of a collection of studies may provide increased confidence in a given risk estimate. The Bradford-Hill criteria listed earlier provides a very valuable checklist in this respect. The greater the number of criteria that can be met, the more confidence there can be in the value of a change in policy/legislation.

11.3.2 Mathematical modelling (quantitative risk assessment)

Mathematical modelling of infectious disease processes has played an increasing role in the field of epidemiology. These models, which describe the disease transmission of specific pathogens, have been used to study directly transmitted diseases (such as measles), vector-borne diseases (such as malaria) and sexually transmitted disease (such as AIDS); however, they have rarely been applied to waterborne diseases. Quantitative risk assessment (QRA) has traditionally used a model structure based on a chemical risk paradigm to estimate the risk of exposure to waterborne pathogens. The limitations of using this approach to assess risk from exposure to pathogens are discussed in Chapter 8. Recently, the QRA approach has been extended using disease transmission models to account for some of those limitations (also discussed in Chapter 8).

Regardless of the model structure used, conclusions based solely on modelling studies can potentially be misleading. This is due to the fact that:

- the huge levels of uncertainty and variability inherent in these environmental systems limit the precision of model prediction
- the limited data available to assess and calibrate the model necessitates the use of a number of assumptions.

One specific concern in respect of the value of QRA relates to the fact that all models described so far concentrate on the risks associated with specific pathogens. To gain estimates of total disease burden, separate models need to be constructed for all possible pathogens. Clearly this is not a trivial task and the uncertainties associated with individual pathogen models would also be combined. Also it is more difficult within QRA to take account of health-related factors that cannot be linked to simple figures of disease numbers. Epidemiological studies can be designed to cover a range of diseases (or symptom complexes) in a single study more easily than QRA. Furthermore, epidemiological studies can be designed to investigate the impact of water on a more holistic definition of health. Thus, models are most useful when used in conjunction with epidemiology. They can provide a valuable framework from which to interpret data and elucidate processes. In this way a model can help generalise empirical findings for relevant policy making. Specifically, these models provide a theoretical framework that can:

- identify data gaps and define research goals
- aid in decision making
- define the sensitivity of these decisions.

11.3.3 Biological and physical sciences

Although rarely expert in these other sciences, public health practitioners frequently call upon the expertise of scientists and engineers from many varied backgrounds. Laboratory sciences, especially microbiology, have had a long association with public health stretching back to the time of Pasteur and Koch. Modern techniques of molecular biology have had a particularly significant impact on public health practice in recent years. With waterborne disease, such recent developments have provided techniques to improve the diagnosis of disease in humans and the detection of pathogens in environmental samples. The ability to distinguish between similar strains has also been improved by the use of molecular 'fingerprinting' methods. Such information can be vital in showing that the agent responsible for an outbreak is the same (or not) as that isolated from a drinking water supply. As is the case for cryptosporidiosis and *E. coli* infections, sub-species typing can be valuable in indicating the likely epidemiology of potentially waterborne outbreaks.

Although the management of water distribution systems is now seldom under the control of public health practitioners, a knowledge of the principles of environmental engineering is essential at times. This is particularly important during outbreaks when public health practitioners and water engineers must work closely together.

11.3.4 Social and behavioural sciences

The social and behavioural sciences have assumed increasing importance for public health practice in recent years as attention has refocused on the importance of lifestyle and social status on health. The social sciences have enabled public health professionals to describe the factors responsible for lifestyle and how these correlate with health. Sociology has also enabled a more accurate description of the factors that divide society and how these are responsible for inequalities in health (Townsend *et al*. 1992).

The behavioural sciences are also of great importance for designing public health interventions that seek to modify personal behaviour patterns through health education.

11.3.5 Demography

Demography is concerned with the structure of and changes in human populations, largely through measuring birth, death and migration. As such, demography has a significant function in public health in defining the setting in which disease occurs. Although in industrially-developed nations, deaths associated with drinking-water are relatively rare, demography is essential in identifying the size and structure of the population at risk. Without this information it would not be possible to identify the burden of disease due to water. For nations with rapid population growth, demography provides a means of predicting future demand for safe drinking water (or, more accurately, predicting the future population without access to safe drinking water).

11.4 PUBLIC HEALTH INTERVENTIONS

As discussed in the introduction to this chapter, and illustrated by the thermostat metaphor, public health practice must lead to interventions that have the potential to improve human health. There are a number of types of intervention that are available to the public health practitioner (Detels and Breslow 1997). These cover a wide variety of possible approaches that are frequently complementary and may be synergistic. Indeed, it is unlikely that any one approach will succeed when used in isolation.

11.4.1 A classification of public health interventions

11.4.1.1 Preventive medical care

One of the most important public health interventions available to society is the provision of adequate medical care. In many societies, the provision of medical care is largely controlled by public health practitioners who determine the health-care needs of their populations and then plan to provide for those needs. Medical care is essential in reducing the burden of disease by ensuring rapid diagnosis and treatment of disease so that the duration of illness, the severity of disability and the risk of death are reduced where possible. As such, the quality of medical care in society has a substantial role to play in reducing the burden of disease associated with the waterborne route. Saving young people from dehydration by provision of adequate health-care at local village level will substantially reduce the burden of disease in those societies.

Particularly for some infectious diseases, medical care can also have a larger impact on the reduction of disease incidence than simply those that benefit directly from the treatment. Rapid diagnosis and treatment of individual cases of infection should limit the time that pathogens are excreted into the environment and so reduce the total amount of infectious agent available to infect new individuals. This may be by the use of antibiotics (e.g. for Shigella dysenteriae or Salmonella typhi infections) or quarantine of infectious individuals.

Vaccination is also a form of medical intervention that has had a major impact on the burden of infectious disease worldwide (e.g. vaccination against polio). However, few vaccination campaigns have had a significant impact on the global risk of waterborne diseases. Vaccines against typhoid and hepatitis A are valuable for protecting travellers when visiting areas of increased prevalence from the risk of these infections. Unfortunately, these vaccines are currently far too costly to be used widely to reduce overall burden of disease.

11.4.1.2 Health education and behavioural modification

Health education has long been a mainstay intervention available to the public health professional. Perhaps the most obvious example of this is the anti-smoking campaigns that have been undertaken by many developed nations. Health education can be used to warn people of the dangers of one or more particularly risky behaviours or can be used to promote generally healthier lifestyles. There are numerous examples of the positive impact of health education in reducing waterborne disease. These include the promotion of breast-feeding, educating people to routinely chlorinate drinking water or to boil it during outbreaks of cholera, encouraging the use of narrow neck vessels in which to store water, and other changes in water handling. Hygiene education and household water treatment present opportunities to empower the poor and reduce their burden of water-related disease, without dependence on outside authorities, within meaningful timeframes and at low cost.

11.4.1.3 Control of the environment

Even before the advent of modern public health and the germ theory of disease, the importance of environmental control in protecting health was recognised by many different societies. Thus, the Romans built aqueducts in order to bring clean water into their cities. It could also be argued that in more recent times, the first intervention of modern public health aimed to control the environment by removing the handle from the Broad Street pump. The aim of environmental control is to protect a population from potentially infectious or noxious agents. For waterborne diseases, we are concerned with ensuring that drinking and recreational water is free from potentially infectious agents, and that human sewage and other wastes are dealt with in as safe a manner as possible. The setting, and implementation, of international guidelines has, in recent years, been a major factor in improving such quality and reducing risk.

11.4.1.4 Cultivating political will

The cost of many possible interventions for reducing waterborne disease can be enormous. For example, a large-scale water treatment works can cost several tens of millions of pounds. Getting the support to spend such large sums requires considerable political persuasion skills. Furthermore, many public health interventions require legislation and must compete with other demands for legislation time. Ever since the days of Chadwick, political skills have been central to the armamentarium of the public health professional. Without such political goodwill, few of the improvements in public health during the last century would have been possible.

11.4.2 Public health interventions and waterborne disease

In general, intervention strategies (such as improvements in sanitation) will not only reduce the disease burden associated with a targeted pathway but will also reduce the disease burden from other pathways by decreasing the amount of contamination. Similarly, many environmental health interventions and most of the water-related interventions discussed in this book act not only on a single pathogen (as would be the case with vaccination for example) but on a variety of pathogens. This is particularly clear in the case of the various pathways that contribute to faecal-oral disease transmission, a route shared by a large number of known and currently unrecognised pathogens (see Chapter 5). The fact that interventions can have effects across different pathways and multiple pathogens has certain implications.

First, dose–response relationships attempt to quantitatively describe the relationship between exposure to a given pathogen and the resulting adverse health effect (see Chapter 8). The implicit assumption when using these dose–response models in a chemical risk assessment paradigm is that by reversing the use of the curve it is possible to predict the outcome of an intervention if its impact on exposure can be estimated. This approach, however, assumes that transmission pathways are independent, which in general is not true. In particular, an intervention in one area may impact on other routes of exposure either beneficially or detrimentally. For example, increasing the volume of available water in order to facilitate hygiene behaviours may decrease infection in children and therefore may decrease recreational water transmission. On the other hand, increased water volume may also result in excess water, increasing the risk of infection from other pathogens. This limitation of the chemical risk paradigm can be addressed by incorporating transmission models as a quantitative framework for risk assessment estimate (see Chapter 8). Since transmission models represent the natural history of the disease process and have biologically-based parameters they can be effectively used alongside epidemiology.

A second implication relevant to the models discussed in Chapter 8 is that they describe pathogen-specific processes. General interventions that operate across a pathway or combination of pathways are therefore likely to have an effect underestimated by a quantitative risk assessment approach (which mostly deals with pathogens on a case by case basis) but which may be detected by epidemiological investigations if appropriate methodologies are employed. This is logical given that microbiological risk assessment focuses on causes of disease whereas epidemiological studies can aggregate causes (pathogens), both known and unknown, by looking directly at the health effects themselves (see Chapter 7).

Third, generalising epidemiological studies to different target populations under different environmental conditions should be looked at carefully. An interesting issue of study design specificity is that there is potentially a competitive effect that arises from the interdependency of transmission pathways. For example, if effective sanitation were introduced then the subsequent impact of water supply or water quality interventions may be reduced. This is supported by the available body of evidence, suggesting that one intervention may reduce the likely exposure through multiple pathways. In Esrey's review (Esrey et al. 1991), water quality was found to be a relatively inefficient intervention. However, in the studies he reviewed water quality was almost invariably an add-on or secondary intervention to, for example, water supply. In contrast, studies where water quality has been treated as a primary intervention, much higher rates of response have been detected (Quick et al. 1999).

Another example that demonstrates the effects of pathway interdependencies is the situation where exposure to a given pathogen (such as the Norwalk-like viruses) is ubiquitous. Under these conditions the impact of a single intervention on public health may be negligible or zero, since the risk has, in effect, transferred from one route of exposure to another. This is most likely to occur in relation to water-related disease where secondary transmission plays a major role and where primary introduction occurs through many different pathways.

To make the best use of available data for policy making, therefore, requires a good understanding of the specific conditions under which each study being considered was conducted. The use of mathematical models for guideline-setting has its own share of limitations, including the assumptions required to develop the model structure and define the parameters. Mathematical models, however, can be useful tools to help with the process of generalising the conclusions of epidemiology studies to other conditions. Specifically, transmission models may be useful in generalising across different environmental conditions. Integrating results from different disciplines can help to address the inevitable limitations that exist when attempting to develop scientifically sound guidelines.

11.4.2.1 Cause-effect

Considerable research efforts are expended in demonstrating cause-effect relationships, and confirmation of cause-effect is an important step in justifying (and sometimes in formulating) control measures. However, the existence of a cause-effect relationship does not mean that the cause is a dominant, or even significant, contributor to overall burden of disease. Demonstration of cause-effect may give a false sense of security regarding the ability to impose control and may discriminate against other causes of equal or potentially greater importance. Within the field of water and health management a 'rule of thumb' which is sometimes quoted is that if a cause contributes less than 5% to the burden of a disease then it should be overlooked in favour of more significant routes. While this ignores the importance of cost-effectiveness, it does illustrate an important point.

11.4.2.2 Environmental health decision-making

As is common in many other areas, the complexities of environmental and specifically water management have led to fragmentation of responsibilities and of professional areas of interest. In the field of water, and indeed within the narrower field of water and health, this means that distinct professional interest groups have developed. The lack of effective communication among these groups is remarkable and was one of the factors that became obvious at the meeting that gave rise to this book. As a result, professional communities concerned with drinking-water quality and human health may be ignorant of developing lines of thought, approaches and information in what are, in fact, closely allied areas such as recreational water use and wastewater reuse. One outcome is an inefficient multiple learning exercise, since lessons learned are not readily transmitted between the largely isolated professional groups concerned.

This trend runs contrary to much current and developing policy that is moving towards the concept and application of 'integrated' management. Failure to create linkages between key interest groups including technical/professional communities will impede the process in general and the achievement of benefits. Integration of environmental health and of water and health concerns in such management approaches has been especially poor. Chapter 15 describes some of the problems associated with cost-benefit and cost-effectiveness analysis including, for example, the difficulties in identifying the many health and non-health benefits that arise from environmental interventions and assignment of both costs and benefits to appropriate sectors. Nevertheless, an empirical basis for an integrated public health outlook on water management is readily available. Thus, for example, substantial commentary exists on the costs of sewage treatment as a public health intervention to reduce the health risks associated with recreational water use. Much of that commentary has highlighted the high costs and limited benefits. Such a viewpoint discriminates against source-related rather than use-related interventions in that it ignores benefits gained through other routes. For example, effective treatment of an upstream sewage discharge in a catchment may increase downstream drinking-water quality, downstream recreational water quality (both in the river and in the receiving coastal area) as well as the water quality in coastal areas used for shellfish farming and harvesting. This demonstrates the importance of integrating public health management across these areas and in particular the need for an integrated public health policy in order to enable rational establishment of health targets as a basis for environmental standard-setting supportive of public health.

11.5 THE PUBLIC-HEALTH-BASED CONTRIBUTION TO SETTING STANDARDS

As the reader should already have gathered, there are a few key features about the public health professional's contribution to standard setting. These are:

- The use of a broad range of skills, tools and disciplines in the standard-setting process.
- Knowledge of a wide range of disease processes and transmission routes beyond those normally considered as waterborne.
- Priority setting, by determining the importance of the adverse health effects of the issue under consideration relative to other public health needs of society.
- A commitment to, and advocacy of, the needs of the relatively disadvantaged and socially excluded sections of society.

Although not directly applicable to international standard-setting, the process of health and environmental impact assessment provides some useful insights (British Medical Association 1998). There are seven guiding principles for health impact assessments (HIA) that are worth restating in this context. Standard setting should be:

(1) Multidisciplinary, including specialists and generalists from within public health and other disciplines.

(2) Participatory: where possible key stakeholders including informed representatives of the general public should have the opportunity of expressing their views.
(3) Equity-focused, in that any changes should aim to minimise health inequalities while improving community health.
(4) Qualitative as well as quantitative, in that many important issues in public health and social well-being are not amenable to direct measurement.
(5) Multi-method, in that a variety of different models and techniques are used in the analysis so no preferred model or study dominates the debate.
(6) Explicit in both values and politics, in that the values and interests of all participants should be disclosed early in the process.
(7) Open to public scrutiny.

A public health perspective should come with the understanding that although these environmental processes are complex and although there are limitations to the tools available to the public health practitioner, decisions must be made. Some suggested activities that should be considered in the decision-making process for environmental standards are listed below:

- Determining the burden of disease (see Chapter 3), which should include the amount of illness and the severity of the impact of that illness on people's lives and the health of communities.
- Assessing the evidence of a relationship between disease and proposed environmental risk factors such as drinking water. Even if a disease has a very high impact on health its control may or may not be amenable to environmental modification by appropriate standard setting. For this we can use epidemiology methodologies (Chapter 7).
- Considering whether the risk of disease is acceptable or not, tolerable or not (see Chapter 10).
- Describing the major determinants of disease in various communities, again detailing why each determinant is important and ranking their importance.
- Considering the availability and capability of health protection and health care facilities in each community.
- Modelling the impact of proposed changes in standards on the main diseases under consideration.

- Considering whether proposed new standards are achievable in the model communities.
- Modelling the economic costs of the proposed new standards.
- Modelling the impact of proposed changes on other public health issues (including issues such as communicable disease, non-communicable disease, injury, mental health and so on).
- Considering any adverse effects on public health of changes in standards (either directly or indirectly through such things as increased unemployment).
- Considering whether there are any non-public health related (such as environmental or wildlife) benefits or drawbacks.
- Considering which other non-water-related interventions might be able to achieve the desired goal (e.g. improved housing, education, employment opportunities and health care provision) and whether available resources would be better directed at these interventions.

11.6 IMPLICATIONS FOR INTERNATIONAL GUIDELINES AND NATIONAL REGULATIONS

In this chapter we have tried to give the reader an overview of public health as it is currently practised. We have also suggested various approaches that could be used when considering the issue of international environmental guideline-setting, taking more of a public health standpoint. We had previously categorised the public health contribution as being holistic, in its sphere of interest and its use of methodologies. The public health contribution is also about priority setting and identifying those areas worthy of intervention. However, of most importance is the advocacy role of public health, particularly for the most vulnerable and socially excluded sections of the population. Today there are many powerful interest and lobby groups that seek to influence national and international governments for their own purposes. In our view, the primary contribution that public health can make to society is to provide a strong voice for those sections of society whose needs and interests may never otherwise be considered.

Despite the evident importance of the national arena, especially in standard-setting and with profound implications for more local activities (see Chapter 16), there is often very limited capacity in national public health administrations to engage adequately. This relates to the resourcing necessary to carry out basic functions (such as surveillance and outbreak investigation), the limited human resources available (both in numbers and expertise) and the fragmentation of expertise. International guidelines and their supportive background documentation provide a form of support to national public health administrations that is invaluable in this role. They provide balanced information gleaned from the overall body of evidence. Of importance may be information regarding causal relationships (between chemical contaminants of drinking water and adverse health effects, for example) and between disease and environmental risk factors. Nevertheless, many of the processes involved in standard-setting are national (even local) in character. These include, for example, determination of tolerable disease burden, and available capacities and capabilities. While local in character, there is a limited stock of high quality studies with which to inform such decision-making. The process of their collation, critical review and dissemination, which takes place during guideline derivation, is also a valuable support to national processes. Finally, many national administrations lack experience in the processes of guidelines/standards derivation and of legislative review (especially with regard to aspects of implementation). The transparent process of guidelines derivation may provide an example with which to inform national processes. Conversely, the omission of certain aspects (such as the adaptation of guidelines to prevailing social, cultural, economic and environmental circumstances, including aspects of progressive implementation) creates a vacuum, and provision of explicit guidance on these would be an asset to national public health authorities in the future.

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