12

System assessment, upgrading systems and new supplies

This chapter examines means for assessing the water system performance against health-based targets, using either quantitative risk assessment or epidemiological approaches. The results of such analyses can be used to target investment for the upgrading of supplies. Additionally, setting up a water safety plan for a new supply is also described.

12.1 ASSESSING AN EXISTING SYSTEM AGAINST HEALTH-BASED TARGETS

The process of assessing a system against established health-based targets is a component of the framework for safe drinking-water (section 1.4). The assessment will provide an estimation of the safety of the supply in relation to potential impact on public health under the existing design and operational conditions. Assessments are generally undertaken through a quantitative risk assessment using data from a range of pathogens, indicator organisms and chemicals. Alternatively, an epidemiological study may be used to evaluate what contribution to disease can be ascribed to the water supply, although this approach may be costly, may not capture the risks associated with infrequent events that may lead to outbreaks and is rarely applied in practice.

The following subsections briefly summarise the process and the reader is referred to the *Guidelines for Drinking-water Quality* (WHO 2004) chapters 3 and 7 and Havelaar and Melse (2003) for more details (including a number of examples).

12.1.1 Quantitative risk assessments

Quantitative risk assessment approaches would typically quantify the potential risks arising from:

- hazards in source waters;
- the impact of the system in reducing the threat posed by source water through source protection and treatment;
- the residual risk from the production stage; and
- risks from recontamination during distribution.

The degree of sophistication of the risk assessment will depend upon available resources. At a very simple level, this may be possible by using a literature-based estimate of the likely removal of pathogens through treatment trains or source protection measures. An example of where this may be done is the use of *Clostridium perfringens* as a surrogate for *Cryptosporidium* removal in treatment works. As the risk posed by a supply, however, is generally influenced to a significant degree by the operational performance in managing the supply, such approaches should not be solely relied upon for individual supplies and may require validation of effectiveness in practice.

Analysis of pathogens within the water quality assessment will provide more reliable risk estimates than is possible using indicator or index organisms alone. This can be done using a set of reference pathogens rather than trying to assess the risk posed by possible pathogens present. This approach uses a selected range of pathogens whose infectivity and persistence in water is such that control of these pathogens would provide confidence that all pathogens of a similar nature had also been controlled. Suggested reference pathogens include *Cryptosporidium parvum*, *E.coli* O157 and rotavirus (WHO 2004).

Raw water quality varies widely between different locations, but also at one location there may well be considerable variation of raw water quality over time. If site-specific data are available, they are best summarized by using the arithmetic mean concentration. Where specific data are not available typical values could be extracted from the literature as shown in Table 12.1.

Table 12.1: Examples of high detectable concentrations (per litre) of enteric pathogens and faecal indicators in different types of source water (WHO 2004)

Pathogen or indicator group	Lakes and reservoirs	Impacted rivers and streams	Wilderness rivers and streams	Groundwater
Campylobacter	20-500	90-2500	0-1100	0-10
Salmonella	-	3-58000 (3-1000)	1-4	-
E. coli (generic)	10 000-1000000	30000 – 80000	6000-30000	0-1000
Viruses	1 – 10	30-60	0-3	0-2
Cryptosporidium	4-290	2-480	2-240	0-1
Giardia	2-30	1-470	1-2	0-1

The (average) concentration of pathogens in drinking-water is calculated by combining the concentration in raw water with the degree of reduction afforded by the treatment processes. Again, the reduction due to various treatment processes can be determined empirically or by taking typical levels from the literature (WHO 2004 – chapter 7). The result of this calculation can be examined against the health-based target, although it may be necessary to convert the result to Disability Adjusted Life Years (DALYs) to account for different pathogen illness severities and to compare against a reference level of 10^{-6} DALYs per person per year (WHO 2004).

This risk estimate essentially represents the risk posed by water as it leaves the treatment works. It may also be useful to make a second estimate based on re-contamination during the distribution system. The latter may be more complicated as it may be undertaken in several ways, depending on the extent of the database and confidence in the results of water quality assessments. It is likely that concentrations will primarily be derived from indicator bacteria and identified physical problems (e.g. cross-connections) within the system. When undertaking the risk assessment in distribution systems, assumptions may have to be made regarding the length of time an event occurred for and estimated numbers of people affected. The former can be derived from a review of response times from reported failures or 'best estimates' and the latter from an understanding of the hydraulics of the water supply.

In countries where universal access to piped water has not been achieved, it will be useful to compare the risk between different types of water supply to gain a full understanding of the true nature of the risk posed by each individual supply. This will prevent, for instance, expenditure on upgrading a piped water supply, which although higher than the reference level is far lower risk than alternative supplies.

12.1.2 Epidemiological approach

An epidemiological approach to reviewing performance against health-based targets will only be used where the health-based targets are expressed primarily in terms of control or a reduction in disease as a result of maintenance or improvement in water safety. As a result, it is likely that this approach will primarily be related to diarrhoeal disease, although it is possible that such approaches may be used for other microbial or chemical contamination. For instance it would be possible to apply this type of approach in communities affected by high arsenic concentration where a switch to arsenic-free water had been implemented, as this can prevent development of further cases or lead to reversal of symptoms.

If an epidemiological study approach is adopted, it is important to consider how this would be most appropriately undertaken. It is unlikely to rely on passive health surveillance, as the complexity of interpreting the results would be difficult, particularly if assessing the risks related to diarrhoeal disease.

The most effective way of using an epidemiological approach is to undertake blinded, randomised case-control studies. A number of such studies have been performed on supplies as a means of evaluating the impact of particular water supplies in developed countries (Payment *et al*. 1991; Hellard *et al*. 2001). The use of such studies has been shown to greatly aid understanding of the impact of the water supply and in identifying whether safety is being maintained. In some settings, however, it is important to recognise that the complexity of the water use patterns and use of alternative sources may make developing definitive answers regarding the impact from a particular water supply difficult to assess.

12.2 USING THE RISK ASSESSMENT DATA FOR INVESTMENT

The purpose of the risk assessment is partly to determine whether it is necessary to upgrade a system so that it will meet the health-based targets. If the risk assessment demonstrates that the supply is failing to meet the targets, then investment should be considered, for instance by optimising existing treatment (LeChevalier and Au 2004) and/or introducing additional treatment processes (Westrell *et al*. 2003). However, one of the greatest benefits of using quantitative risk assessment approaches is that a detailed breakdown of where risks occur can be made. As a result better informed decisions can be made regarding where investment would deliver the greatest gains. The risk assessment should provide details on the performance of individual processes in the catchment and in removing pathogens or chemicals. It will also provide an indication of what increases in risk result within the distribution network and where within the network these occur. This allows targeted investment that will address the causes of increases in risk and therefore deliver cost-effective risk reductions.

The system risk assessment may not automatically result in the need for new capital investment, but highlight opportunities to meet targets through improving operational procedures. Resolving these and improving performance may deliver the risk reduction required to meet the health-based targets. Where the risk assessment indicates a need for capital investment, other factors should also be considered, including the actual level of risk posed by the safety of the water supply. For instance, if parts of the population only have a communal level of service (i.e. public tap) or no access to the water supply then investment in increasing level of service may often bring greater health gains than improving water safety unless the risk estimate from degraded water safety is very high. Similarly, if there is a lack of sanitation, investments in this will generally deliver greater health gains than reducing risks from water supply, unless these are at a very high level. Investment decisions need to be considered in the light of comparative risk assessment in order that balanced decisions are made. Where investment appears warranted, this will not be likely to happen immediately and therefore the supplier will also need to develop interim plans to manage the risk until the capital investment has been achieved.

12.3 PREPARING A WATER SAFETY PLAN FOR NEW SUPPLIES

As noted in Chapter 1, the majority of water safety plans will be defined for existing water supplies. However, there will be a number of new water supplies or rehabilitation projects that are developed for which water safety plans will need to be defined. Water safety plans for new systems will be able to draw, to a large extent, on the knowledge gained from developing and implementing water safety plans in existing supplies. There may be some exceptions to this, for instance where new treatment technologies are deployed. In these cases, validation of new processes and technologies is essential and must be provided as supporting evidence to the water safety plan when this is under review.

Data on source water quality will provide the basis from which to select the combination of treatment processes and/or other interventions to deliver water that meets the health-based targets. In order to do this, the starting point is the reference level of risk that has been determined as tolerable. This is the health-based target expressed in DALYs, e.g. the WHO reference level of risk for infection is 10^{-6} DALYs /person/year, which is effectively the same level of risk as the 10^{-5} excess cancer risk used as the basis for deriving guideline values for carcinogens. As with the risk assessment used to examine existing systems (section 12.1.1) this risk level can be used to define a tolerable concentration of pathogens or substances in the final drinking-water produced.

It is logical that the design of the new water supply will be in part determined by the water safety plan outlined. Therefore, it is essential to have data on the source water quality and preferably the concentration of reference pathogens and toxic chemicals. Data should ideally be collected that reflect seasonal and other fluctuations and which provide information on a range of potential pathogens. The latter may use 'reference' pathogens (such as *Cryptosporidium parvum*, *E.coli* O157 and rotavirus) that will represent particular challenges to the supply and the population served in terms of their infectivity and persistence in water. Alternatively, data may be collected on a range of indicator organisms (e.g. *E.coli*, bacteriophages and *Clostridium perfringens*) that could be used as surrogates for pathogen behaviour. In addition, data would also be needed on a range of physio-chemical parameters (turbidity, conductivity, pH, temperature) as well as any toxic chemical thought likely to be present.

By using data on pathogen and chemical concentration in source waters and comparing this to the concentration required to meet the health-based target, the required log reduction that should be achieved during water production can be calculated. This is illustrated in Table 12.2, for three different pathogens. The scientific literature can be consulted to determine what reductions can be achieved through different treatment processes.

Table 12.2: Linking tolerable disease burden and source water quality for reference pathogens: example calculation

River water (human and animal pollution)		*Cryptosporidium*	*Campylobacter*	Rotavirus[a]
Raw water quality (C_R)	Organisms per litre	10	100	10
Treatment effect needed to reach tolerable risk (PT)	*Percent reduction*	*99.994%*	*99.99987%*	*99.99968%*
Drinking-water quality (C_D)	Organisms per litre	6.3×10^{-4}	1.3×10^{-4}	3.2×10^{-5}
Consumption of unheated drinking-water (V)	Litres per day	1	1	1
Exposure by drinking-water (E)	Organisms per day	6.3×10^{-4}	1.3×10^{-4}	3.2×10^{-5}
Dose–response (r)	Probability of infection per organism	4.0×10^{-3}	1.8×10^{-2}	2.7×10^{-1}
Risk of infection ($P_{inf,d}$)	Per day	2.5×10^{-6}	2.3×10^{-6}	8.5×10^{-6}
Risk of infection ($P_{inf,y}$)	Per year	9.2×10^{-4}	8.3×10^{-4}	3.1×10^{-3}
Risk of (diarrhoeal) illness given infection ($P_{ill\|inf}$)		0.7	0.3	0.5
Risk of (diarrhoeal) illness (P_{ill})	Per year	6.4×10^{-4}	2.5×10^{-4}	1.6×10^{-3}
Disease burden (db)	DALYs per case	1.5×10^{-3}	4.6×10^{-3}	1.4×10^{-2}
Susceptible fraction (f_s)	Percentage of population	100%	100%	6%
Disease burden (DB)	DALYs per year	1×10^{-6}	1×10^{-6}	1×10^{-6}
Formulas:	$C_D = C_R \times (1 - PT)$ $E = C_D \times V$ $P_{infd} = E \times r$			

[a] Data from high-income regions. In low-income regions, severity is typically higher, but drinking-water transmission is unlikely to dominate.

The above deals directly with the production of water, however, the distribution systems of new water supplies will be subject to potential ingress, although not at the same level as existing systems. This should be taken into account in some manner in order to develop an improved risk assessment of the water supply. One approach may be to allow a tolerable degradation of water quality within distribution systems, for instance by assuming a certain number of contamination events occurring each year and estimating the numbers of people that would be expected to be affected. However, such approaches are difficult to deploy without data from the supply on contamination events and their frequency. It is therefore more appropriate within the water safety plan to define the ways in which potential hazardous events will be controlled. It is also useful, however, to ensure that a system of recording failures (e.g. leaks, water quality deterioration) is in place, in order to allow data to be collected to fit into a risk assessment model at a later date.