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Introduction

Waterborne disease remains one of the major health concerns in the world. Diarrhoeal diseases, which are largely derived from contaminated water and inadequate sanitation, account for 2.4 million deaths each year and contribute over 73 million Disability Adjusted Life Years (a measure of disease burden, WHO 1999). On a global scale, this places diarrhoeal disease sixth in the list of causes of mortality and third in the list of morbidity. This health burden is primarily borne by the populations in developing countries and by children.

Based on present estimates, one-sixth of humanity lack access to any form of safe and improved water supply within 1 kilometre of their home and one-fifth of humanity lack access to any form of adequate and improved excreta disposal (WHO and UNICEF 2000). Endemic and epidemic disease derived from unsafe water supply affects all nations. Outbreaks of waterborne disease continue to occur in both developed and developing countries, leading to loss of life, disease and economic burden for individuals and communities. Strategies to improve water quality, in conjunction with improvements in excreta disposal and personal hygiene can be expected to deliver substantial health gains in the population.

In addition to microbial risks to drinking-water, safety may also be compromised by chemical and radiological constituents. The World Health Organization *Guidelines for Drinking-water Quality* (GDWQ), for which this text is a supporting document, aim to protect public health and a key way to ensure this is through the adoption of a water safety plan.

The Millennium Development Goals articulated by the General Assembly of the United Nations (2000), include a commitment to reduce by half the proportion of the World's population who are unable to reach or afford safe drinking-water by 2015.

The definition of what is safe is therefore of key importance in assessing whether this target has been achieved. The use of water safety plans should greatly enhance the confidence of policy makers and sector stakeholders that the target has genuinely been achieved and contributes to the improved public health and reduced poverty. Furthermore, the right to water (UN 2003) places a clear responsibility on Governments to ensure access to safe and adequate water supplies.

Although better health protection is reason in its own right for the adoption of strategies to improve drinking-water quality, international policy is also a key factor. Water suppliers have a duty of care to persons utilising the water or service that they supply and therefore, need to be aware of the regulatory and policy framework within which they must operate including common law (where appropriate), statute, policy, guidelines and best management practice. In this document, a methodology is laid out for the management of the risks to public health from the water supply. However, the management of water supply businesses or operations also needs to be conducted with an associated knowledge of the risks of not working within the legal and other frameworks. Water suppliers should therefore acquit their operation in a duly diligent manner such that reasonably foreseeable harm is identified, prevented and reasonable measures are taken to protect the consumer.

1.1 WORLD HEALTH ORGANIZATION GUIDELINES

Worldwide the principal starting points for the setting of water quality standards are the World Health Organization Guidelines (WHO), as shown in Box 1.1 (Box 1.1).

The Guidelines are, in large part, health risk assessments and are based on scientific consensus, best available evidence and broad expert participation. The need for harmonisation in the development of the three water-related guideline areas for the control of microbial hazards was recognized in the late 1990s (Fewtrell and Bartram 2001).

Box 1.1: World Health Organization Guidelines concerned with water quality

Guidelines for Drinking-water Quality
First published in 1984-1985 in three volumes to replace earlier international standards.

Volume 1: Recommendations
Volume 2: Health Criteria and other Supporting Information
Volume 3: Surveillance and Control of Community Supplies.

Second Editions of the three volumes were released in 1993, 1996 and 1997 respectively, with addenda to volumes 1 and 2 covering selected chemicals and microbiological agents released in 1998, 1999 and 2002. The third edition of the Guidelines for Drinking-water Quality was published in 2004 as volume 1; background information on specific pathogens and toxic chemicals are on the internet; and a series of supporting volumes.

Guidelines for the Safe Use of Wastewater, Excreta and Greywater
The first edition was published in 1973; the second edition was published in 1989 and the third edition will be published as five volumes in 2005 (except for Volume 5 to be published in 2006).
Vol. 1. Policy and Regulatory Issues
Vol. 2. Aquaculture
Vol. 3. Agriculture
Vol. 4. Excreta and Greywater
Vol.5 Sampling and Laboratory Aspects

Guidelines for Safe Recreational Water Environments
These have been prepared progressively from 1994. Volume 1: Coastal and Freshwaters was published in 2003. Volume 2: Swimming pools, spas and similar recreational water environments was published in 2005.

The resulting framework (Bartram *et al*. 2001), which is illustrated in simplified form in Figure 1.1, is an iterative cycle that encompasses assessment of public health concerns, risk assessment, the establishment of health-based targets and risk management. Feeding into this cycle is the determination of environmental exposure and the estimation of what constitutes a tolerable (or acceptable) risk.

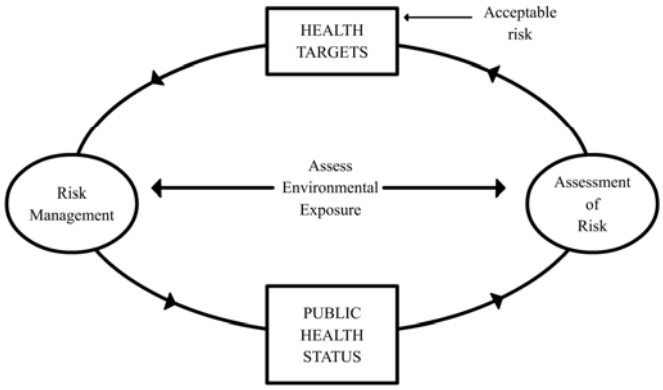

Figure 1.1: Simplified framework (Bartram *et al.* 2001)

Consideration of the risk management process results in an expanded version of the framework.

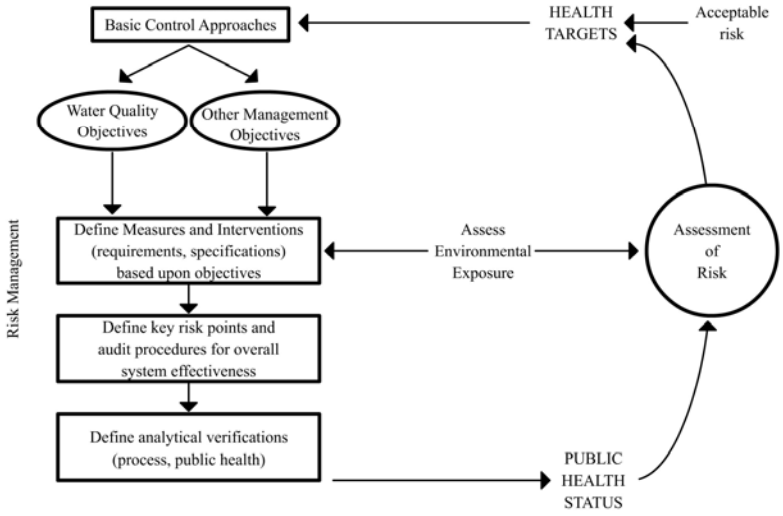

Figure 1.2: Expanded framework (Bartram *et al.* 2001)

1.2 CURRENT MANAGEMENT APPROACHES

There is a wide range of both chemical and microbial contaminants that may be found in drinking-water, some of which can have adverse health effects on consumers.These can be derived from a number of sources including, in some instances, the water treatment process. Understanding the nature of sources of contamination and how these may enter the water supply is critical for assuring water safety. For instance, arsenic has become a major international concern in groundwater where it occurs from a geological source and it is primarily controlled through source selection.

Water supply systems can be considered as a number of steps aimed at assuring the safety of drinking-water, including:

- preventing pollution of source waters;
- selective water harvesting;
- controlled storage;
- treatment prior to distribution;
- protection during distribution; and
- safe storage within the home and, in some circumstances, treatment at the point of use.

These steps can function as barriers, where activities are designed to minimise the likelihood of contaminants entering the water supply or reduce or eliminate contaminants already present in the supply. With the multiple barrier approach, each barrier provides an incremental reduction in the risk of water becoming unsafe. If there is a failure at one point, the other barriers continue to provide protection.

An important strategy in providing safe drinking-water for the consumer is the multiple barrier approach (Teunis *et al.* in preparation) the application of which is often restricted to the actual water treatment process. As the detection and enumeration of pathogenic microorganisms from microbially contaminated water is both difficult and costly reliance has traditionally been placed on the examination for microbial indicators of pollution (Dufour *et al*. 2003). These indicators are usually non-pathogenic bacteria, which are present in faecal material in large amounts. Their enumeration is relatively easy and inexpensive (in comparison with that for individual pathogens). Microbial contaminants, however, are not limited to bacteria and illness may result from exposure to pathogenic viruses or protozoa, both of which have different environmental behaviour and survival characteristics to bacteria. This, coupled with the fact that testing of water immediately prior to, or within, distribution (end product testing) can only highlight a potential health problem after the water has been consumed, has led to the recognition of the need to adopt additional approaches to assuring water quality and safety.

1.3 THE BASIS FOR WATER SAFETY

The most cost-effective and protective means of consistently assuring a supply of acceptable drinking-water is the application of some form of risk management based on sound science and supported by appropriate monitoring as outlined in Figures 1.1. and 1.2. It is important that risk management is inclusive and, therefore, needs to cover the whole system from catchment to consumer (Figure 1.3).

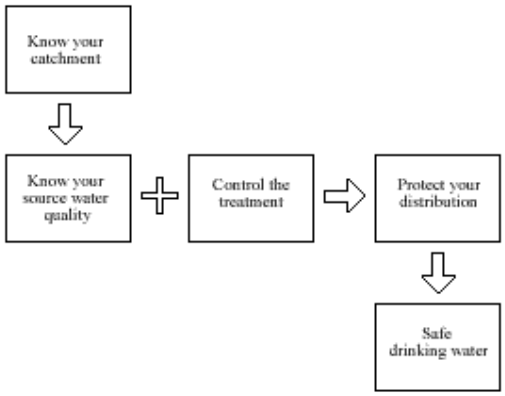

Figure 1.3: 'Catchment to consumer' approach to risk management of the safety of drinking-water (Medema *et al*. 2003)

The risk management approach that was outlined in Figure 1.2 was based largely upon HACCP (Hazard Analysis and Critical Control Point). The principles of HACCP (which is a preventive risk management system that has been used in the food manufacturing industry for a number of decades) are based on developing an understanding of the system, prioritising risks and ensuring that appropriate control measures are in place to reduce risks to an acceptable level. These principles have been refined and tailored to the context of drinking-water following the application of HACCP by several water utilities including in the US (Barry *et al*. 1998) and Australia (Deere and Davison 1998; Gray and Morain 2000; Deere *et al*. 2001). The experience of the application of HACCP by water utilities has informed the development of the water safety plan approach.

1.4 FRAMEWORK FOR SAFE DRINKING-WATER AND WATER SAFETY PLANS

The *Guidelines for Drinking-water Quality* WHO (2004) outlines, a preventive management framework for safe drinking-water that comprises five components (summarised in Box 1.2 and Figure 1.4), three of which combine to form the water safety plan.

Key components:

- Health based targets (based on an evaluation of health concerns).
- System assessment (to determine whether the water supply chain (from source through treatment to the point of consumption) as a whole can deliver water of a quality that meets the health-based targets.
- Operational monitoring of the control measures in the supply chain, which are of particular importance in securing drinking-water safety.
- Manangement plans (documenting the system assessment and monitoring; describing actions to be taken in normal operation and incident conditions – including upgrade and improvement), documentation and communication.
- A system of independent surveillance that verifies that the above are operating properly.

Box 1.2: Framework for safe drinking-water (WHO 2004)

A water safety plan, therefore, comprises system assessment and design, operational monitoring and management plans (including documentation and communication).

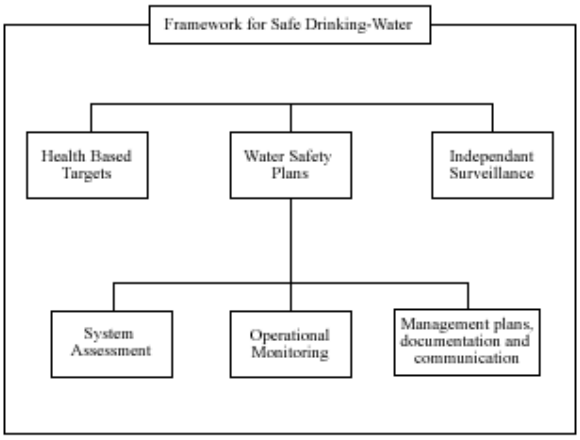

Figure 1.4: Framework for safe drinking-water

1.4.1 Health-based targets

Health-based targets provide the basis for the application of the Guidelines to all types of water supply. The purpose of setting targets is to mark out milestones to guide and chart progress towards a predetermined health and/or water quality goal. They are an integral part of health policy development.

Health-based targets provide a 'benchmark' for water suppliers. They provide information against which to evaluate the adequacy of existing installations and assist in identifying the level and type of inspection and analytical verifications appropriate and in developing auditing schemes. Health-based targets underpin the development of water safety plans and verification of their successful implementation.

In reality the process of target establishment and water safety plan definition is likely to be iterative with each feeding into the other. Health-based targets represent the overall policy objective for water safety as defined by what is considered an acceptable level of risk (e.g. WHO guidelines for carcinogens use 10^{-5} excess lifetime risk of cancer and microbiological recommendations apply 10^{-4} excess annual risk of infection, these targets are broadly equivalent in terms of health burden). However, if a water supply(s) cannot meet health-based targets this does not mean that a water safety plan cannot be defined. A water safety plan should be defined and an estimate made of current risk excess. From this, two policy decisions may emerge. Firstly, there is an investment programme to upgrade the infrastructure or operating procedures, or invest in catchment management, that will ensure the water safety plan will meet the targets (with appropriate relaxations and exemptions in place during the interim). Secondly the excess risk may be accepted because it is shown to be a relatively low contributor to overall national disease burdens and the costs of reducing the excess would divert funds away from other activities with a better prognosis for public health gain. Equally, as water safety plans are developed, health-based targets may be revised in light of new levels of safety that may be achieved. For instance, if investment has reduced microbial risks to below the maximum acceptable level of risk (i.e. 10^{-4} excess annual risk of infection), to prevent unwarranted degradation in service the health-based target would be revised in line with what is considered reasonable to achieve.

Different types of target will be applicable for different purposes so that in most countries several types of targets may be used for various purposes. In developing countries care must be taken to develop targets that account for the exposures that contribute most to disease. Care must also be taken to reflect the advantages of progressive, incremental improvement that will often be based on multiple categorisation of systems to broad categories of public health risk rather than having a single but hard to achieve health-based target at the upper end. In addition, even for a system that cannot achieve a desired health-based target, the implementation of a water safety plan can assist in operating that system optimally, to minimise the incidence of disease attributable to that particular system.

Constituents of drinking-water may cause adverse health effects from single exposures (e.g. microbial pathogens) long-term exposures (e.g. many chemicals). Due to the range of constituents in water, their mode of action, and nature of fluctuations of concentrations, there are four principle types of health-based targets used as a basis for identifying safety requirements (outlined below and in Table 1.1).

- **Health outcome targets**: In some circumstances, especially where water-related/water borne disease contributes to a measurable burden, reducing exposure through drinking-water has the potential to appreciably reduce overall incidence of disease. In such circumstances it is possible to establish a health-based target in terms of a quantifiable reduction in the overall level of

disease. This is most applicable where adverse effects follow shortly after exposure, are readily and reliably monitored and where changes in exposure can also be monitored readily and reliably. This type of health outcome target is primarily applicable to some microbial hazards in developing countries and chemical hazards with clearly defined health effects largely attributable to water (e.g. fluoride). In other circumstances health outcome targets may be the basis for evaluation of results through quantitative risk assessment models. In these cases, health outcomes are estimated based on information concerning exposure and dose-response relationships. The results may be employed directly, as a basis for the specification of water quality targets or provides the basis for development of other health-based targets.

- **Water quality targets**: Established for individual drinking-water constituents which represent a health risk from long-term exposure and where fluctuations in concentration are small or occur over long periods. They are typically expressed as Guideline values (concentrations) of the chemicals of concern.
- **Performance targets**: Performance targets are employed as part of the drinking-water management system for constituents where short-term exposure represents a public health risk, or where large fluctuation in numbers or concentration can occur over short periods of time with significant health implications. They are typically expressed in terms of required reductions of the substance of concern or effectiveness in preventing contamination.
- **Specified technology targets**: National regulatory agencies may establish targets for specific actions for smaller municipal, community and household water supplier. Such targets may identify specific permissible devices or processes for given situations and/or generic drinking-water system types.

Table 1.1: Health-based targets

Type of Target	Nature of target	Typical applications	Assessment
Health Outcome			
epidemiology based	Reduction in detected disease incidence or prevalence	Microbial or chemical hazards with high measurable disease burden largely water-associated	Public health surveillance and analytical epidemiology
risk assessment based	Tolerable level of risk from contaminants in drinking-water, absolute or as a fraction of the total burden by all exposures	Microbial or chemical hazards in situations where disease burden is low and cannot be measured directly	Quantitative risk assessment
Water Quality			
	Guideline value applied to water quality	Chemical constituents found in source waters	Periodic measurement of key chemical constituents to assess compliance with relevant guideline values.
	Guideline values applied in testing procedures for materials and chemicals	Chemical additives and by-products	Testing procedures applied to the materials and chemicals to assess their contribution to drinking-water exposure taking account of variations over time.
Performance			
	Generic performance target for removal of group of microbes	Microbial contaminants	Compliance assessment through system assessment and operational monitoring
	Customised performance targets for removal of groups of microbes	Microbial contaminants	Individually assessment would then proceed as above reviewed by public health authority; would then proceed as above

Type of Target	Nature of target	Typical applications	Assessment
	Guideline values applied to water quality	Threshold chemicals with effects on health which vary widely (e.g. nitrate and cyanobacteria)	Compliance assessment through system assessment and operational monitoring
Specified technology			
	National authorities specify specific processes to adequately address constituents with health effects (e.g. generic/model water safety plans for an unprotected catchment)	Constituents with health effect in small municipalities and community supplies	Compliance assessment through system assessment and operational monitoring

It is important that health-based targets, defined by the relevant health authority, are realistic under local operating conditions and are set to protect and improve public health. Health-based targets underpin development of water safety plans and provide information with which to evaluate the adequacy of existing installations and assist in identifying the level and type of inspection and analytical verifications appropriate. Further details on health-based targets are covered in Chapter 3 of *Guidelines for Drinking-water Quality*.

1.4.2 Water safety plan

The objectives of a water safety plan are to ensure safe drinking-water through good water supply practice, that is:

- to prevent contamination of source waters;
- to treat the water to reduce or remove contamination that could be present to the extent necessary to meet the water quality targets; and
- to prevent re-contamination during storage, distribution and handling of drinking-water.

The focus of this document is the development and implementation of water safety plans to be used by the water supplier. This document provides guidance on how water safety plans can be developed for a range of water supply types.

1.4.3 Surveillance

The third main element of the framework for safe drinking-water is surveillance (covered in more detail in Chapter 5 of the *Guidelines for Drinking-water Quality*).

Surveillance is the continuous and vigilant public health assessment and overview of the safety and acceptability of drinking-water supplies.

Surveillance contributes to the protection of public health by promoting improvement of the quality, quantity, access, affordability, and continuity of water supplies and is complementary to the quality control function of the drinking-water supply agency. Surveillance does not remove or replace the responsibility of the water supplier to ensure that a water supply is of acceptable quality and meets pre-determined health-based and other performance targets.

One of the roles of surveillance is to allow for legal redress in pursuing safe drinking-water. Surveillance is also used to ensure that any transgressions that may occur are appropriately investigated and resolved. In many cases, it will be more appropriate to use surveillance as a mechanism for collaboration between health agencies and water suppliers on improving water supply rather than resorting to enforcement, particularly where the problem lies mainly with community-managed water supplies.

Surveillance requires a systematic programme of surveys that may include auditing of water safety plans, analysis, sanitary inspection and institutional and community aspects. It should cover the whole of the water supply system, including sources and activities in the catchment, transmission infrastructure (whether piped or unpiped), treatment plants, storage reservoirs and distribution systems.