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Water Safety Plans

Managing drinking-water quality from catchment to consumer

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List of abbreviations

ADWG	Australian Drinking Water Guidelines
BWSA	Bulk water supply agreement
CT	Concentration x time (disinfection)
DFID	Department for International Development (UK)
GCW	Gold Coast Water (Australia)
GDWQ	Guidelines for Drinking-water quality
GL	Giga litres
HACCP	Hazard Analysis and Critical Control Point
HPC	Heterotrophic Plate Count
HU	Hazen Unit
ISO	International Organization for Standardization
MAK	Makerere University (Uganda)
MW	Melbourne Water (Australia)
NHMRC	National Health and Medical Research Council (Australia)
NTU	Nephalometric turbidity unit
NWSC	National Water and Sewerage Corporation (Uganda)
O&M	Operation and maintenance
OSUL	Ondea Services Uganda Limited (Uganda)
PHAST	Participatory health and sanitation transformation
SCADA	Supervisory control and data acquisition
SOP	Standard operating procedure
USEPA	United States Environmental Protection Agency
WEDC	Water, Engineering and Development Centre (UK)
WHO	World Health Organization
WQCD	Water Quality Control Department (Uganda)
WSP	Water safety plan

Foreword

The first World Health Organization (WHO) publication dealing specifically with drinking-water quality was published in 1958 as *International Standards for Drinking-water.* It was subsequently revised in 1963 and in 1971 under the same title. In 1984-85, the first edition of the WHO *Guidelines for Drinking-water Quality* (GDWQ) was published in three volumes:

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

The second editions of the three volumes of the *Guidelines* were published in 1993, 1996 and 1997, respectively. Addenda to the first and second volumes were published in 1998, addressing selected chemicals only. An addendum on microbial aspects reviewing selected microorganisms was published in 2002.

The primary aim of the GDWQ is the protection of public health. The GDWQ provide an assessment of the health risk presented by microorganisms, chemicals and radionuclides present in drinking-water. The guideline values recommended for individual constituents of water are not mandatory limits – they are intended to be used in the development of risk management strategies, including national or regional standards developed in the context of local or national environmental, social, economic and cultural conditions. Such strategies, if properly implemented, will ensure the safety of drinking-water supplies through the elimination, or reduction to an acceptable concentration, of constituents of water that are known to be hazardous to health.

It was recommended in 1995 that the GDWQ undergo a rolling revision process. Through this process, microbes and chemicals are subject to periodic review, and documentation related to aspects of protection and control of drinking-water quality is prepared progressively. This process was initiated at a meeting of the Coordinating Committee for the Rolling Revision of the GDWQ, at which three working groups (namely the Microbial Aspects working group, the Chemical Aspects working group and the Aspects of Protection and Control of drinking-water quality working group) were established.

The Coordinating Committee adopted the following:

- a plan of work for the development of the 3rd Edition of the GDWQ and their subsequent rolling revision;
- a plan of work for the development of supportive materials for implementation of the GDWQ; and
- a Procedures Manual for the conduct of the preparation of the third edition of the GDWQ and their subsequent rolling revision.

The programme of work of the Microbial Aspects working group was adopted directly by the 1995 Coordinating Committee meeting. In its first phase of work, review documents on a number of specific microbes were prepared. A future strategy for major revision of the microbial aspects of the WHO water-related guidelines, including the GDWQ, was also developed.

The Chemical Aspects working group considered a wide range of different potential chemical contaminants classified broadly in relation to the source of contamination and the route to drinking-water, in order to aid consideration of risk assessment and management options, as follows:

- naturally occurring chemicals (which include the majority of the most important chemical contaminants with regard to public health);
- chemicals from industrial sources and human dwellings;
- chemicals from agriculture; and
- chemicals used in water treatment or materials in contact with drinking-water.

The working group on Aspects of Protection and Control met in 1996 (Bad Elster, Germany) and in 1998 (Medmenham, UK). The terms of reference of the working group have been established, and five institutions assist in the coordination of the principal thematic areas of work as follows:

- resource and source protection (Federal Environmental Agency, Berlin);
- materials and chemicals used in the production and distribution of drinking-water (NSF-International);
- water treatment (WRc, UK); and
- monitoring and assessment (Robens Centre, UK; VKI, Denmark).

All of these institutions are WHO Collaborating Centres concerned with water. A plan of work has been pursued, based initially upon the recommendations of the Coordinating Committee. This has included the development of a series of documents (principally relating to good practice in achieving the safe conditions described in the GDWQ) and organization of meetings.

During the revision of the WHO *Guidelines for Drinking-water Quality* leading to the 3rd edition, the value of the Water Safety Plan (WSP) approach has repeatedly been highlighted. The potential for water safety plan application has been evaluated in a series of expert review meetings in Berlin (2000), Adelaide (2001) and Loughborough (2001). This document describes the water safety plan approach and further substantiation is provided in a set of companion volumes addressing source protection, treatment processes (at supply and household level), distribution of drinking-water and selection of parameters and analytical methods. Key supporting texts include:

- Impact of treatment on microbial water quality. Mark LeChevalier and Kwok-Kueng Au.
- Protecting groundwater for health: a guide to managing the quality of drinking-water sources. Oliver Schmoll, Guy Howard, Ingrid Chorus and John Chilton (editors).

- Protecting surface water for health: managing the quality of drinking-water sources. I. Chorus, O. Schmoll, D. Deere, S. Appleyard, P. Hunter and J. Fastner (editors)
- Assessing microbial safety of drinking-water. Improving approaches and methods. Al Dufour, Mario Snozzi, Wolfgang Koster, Jamie Bartram, Elettra Ronchi and Lorna Fewtrell (editors).
- Managing water in the home: accelerated health gains from improved water supply. Mark D. Sobsey.
- Microbiological water quality in piped distribution systems. A review of knowledge and practices. R. Ainsworth (editor).
- Heterotrophic plate counts and drinking-water safety. The significance of HPCs for water quality and human health. J. Bartram, J. Cotruvo, M. Exner, C. Fricker and A. Glasmacher (editors).
- Chemical safety of drinking-water: assessing priorities for risk management. T. Thompson, J. Fawell, S. Kunikane, D. Jackson, S. Appleyard, P. Kingston and P. Callan (editors).

This book is aimed at practitioners at all levels. It is especially relevant to water quality managers, regulators (including those people responsible for putting together guidance notes on interpretation), auditors, consultants and international organizations.

1

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.

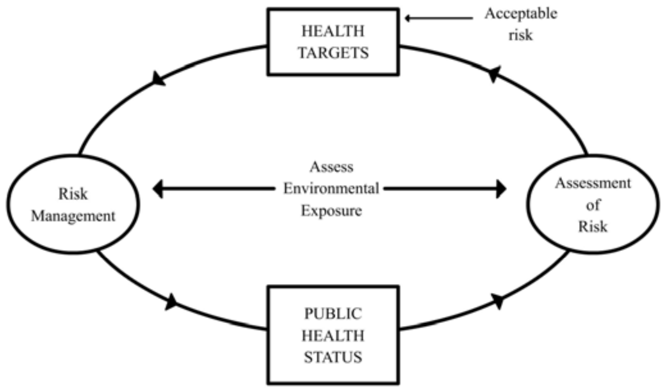


Figure 1.1: Simplified framework (Bartram *et al*. 2001)

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

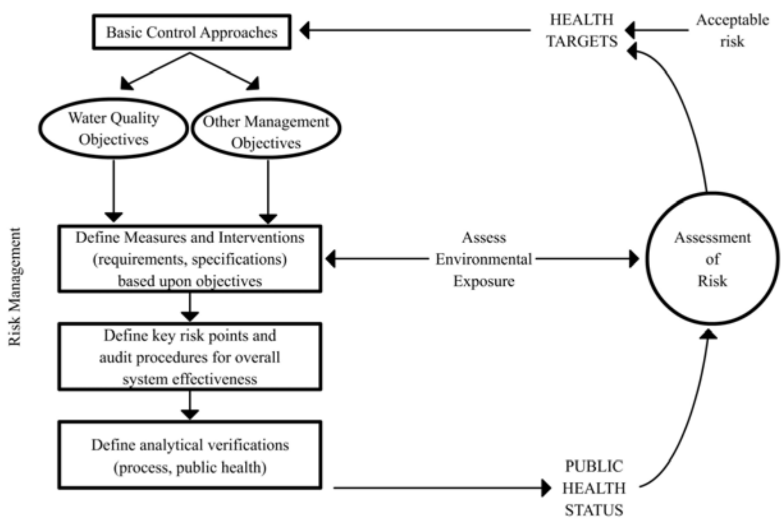


Figure 1.2: Expanded framework (Bartram *et al*. 2001)

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).

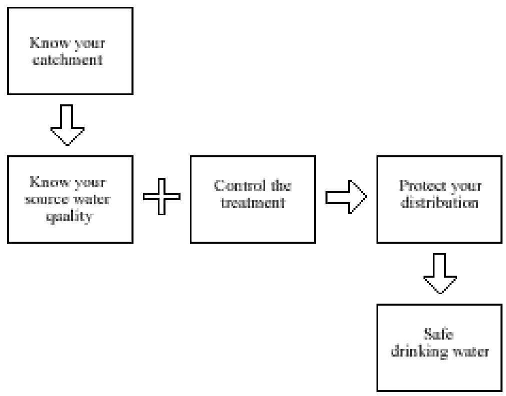


Figure 1.3: 'Catchment to consumer' approach to risk management of the safety of drinking-water (Medema *et al*. 2003)

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).

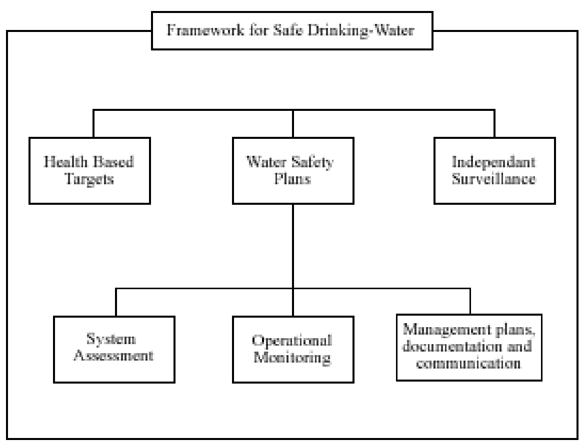


Figure 1.4: Framework for safe drinking-water

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.

2

Roles, responsibilities and legal aspects

There are a number of stakeholders who play an important role in the provision of safe drinking-water, these include public health authorities, local authorities and water supply agencies. The roles and responsibilities of each of these stakeholders are examined in turn. The legal aspects of drinking-water supply, and the role that water safety plans may play, are covered in a separate section.

2.1 ROLES AND RESPONSIBILITIES IN THE PROVISION OF SAFE DRINKING-WATER

As many aspects of drinking-water quality management are often outside the direct responsibility of the water supplier, it is essential that a collaborative multi-agency approach be adopted to ensure that agencies with responsibility for specific areas within the water cycle are involved in the management of water quality. One example is where catchments and source waters are beyond the drinking-water supplier's jurisdiction. Consultation with other authorities will generally be necessary for other elements of drinking-water quality management, such as monitoring and reporting requirements, emergency response plans and communication strategies.

Major stakeholders that could affect or be affected by decisions or activities of the drinking-water supplier should be encouraged to coordinate their planning and management activities where appropriate. These could include, for example, health or resource management agencies and consumers, industry and plumbers. Appropriate mechanisms and documentation should be established for stakeholder commitment and involvement.

Further information on roles and responsibilities in drinking-water safety management is available in WHO Guidelines for Drinking-water Quality, volume 1, 3rd edition, pages 8-18.

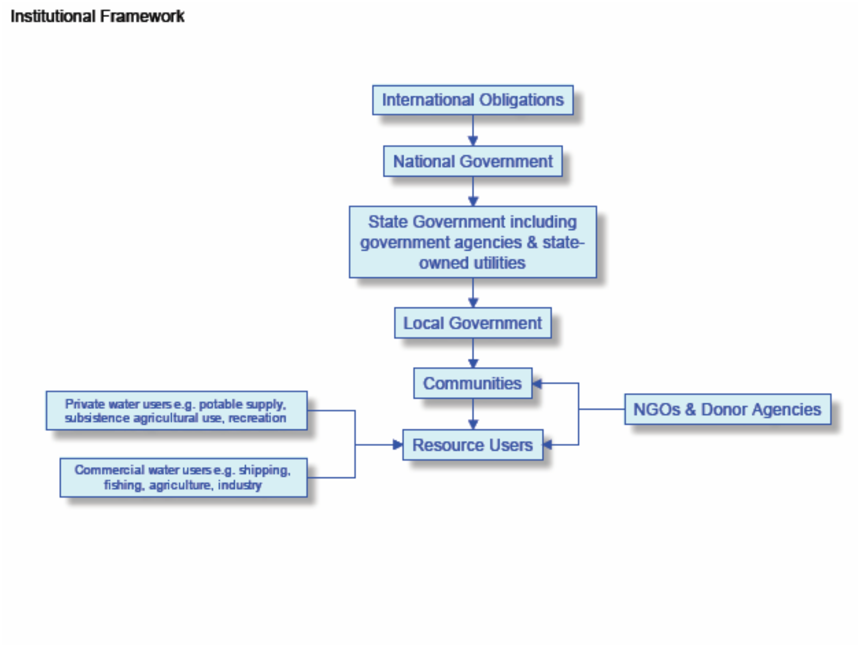


Table 1.1 Example overview of legal and health liabilities associated with water products (developed from Moore, 2003; Davison and Pryor, 2003; Davison and Deere, 2004 and Davison, Davis and Deere, 1999)

Area	Sub-component	Specifics
Common law liability in tort	Negligence	Negligent liability could be incurred in relation to harm caused to: •Human health;•property; or •livestock health as a result of a utility supplying reclaimed water. Each of the elements of common law negligence still has to be proved (on the balance of probabilities). Duty of care is a key aspect of negligence. For instance, a utility may have a duty of care not only to those it supplies reclaimed water to but also a wider group which could include: •Neighbouring landowners; and •those who have access to land irrigated with reclaimed water or even those who have gained access to the land without permission. Duty of care will be determined on a case by case basis but for the utility, the standard of that duty is likely to involve a risk-based approach including: •Understanding the system it is operating; •Understanding the inherent risks in that system; and •The taking of reasonable steps to manage those risks.
	Nuisance	Nuisance liability may arise where a neighbouring landowner's land is affected by: •Pollution of soil from the application of reclaimed water; and/or •Pollution of water from the application of reclaimed water. In general, liability rests with the person from which the nuisance emanates although liability may also be incurred by a party on land under the occupation and control of another.
	Trespass	Trespass involves the interference with a property owner's right to exclusive use of their property. A utility may face claims of trespass in relation to sewer overflows, odour issues and other impacts on neighbours (Slaughter and Farlegih, 2003).
	Misfeasance in public office	Utilities are often public bodies. Where public officers intentionally misuse their powers, an action of tortious misfeasance in public office can be bought. Public officers need to ensure the required power to exercise their authority and that they undertake their duties diligently.
Contract liability	Contractual terms	Utilities enter into contracts with customers. Breach of contractual terms relating to the quality and quantity of a water product is likely to constitute an area of liability for the utility. It is important to expressly state what is and is not covered in any contractual agreement with the user of the water subject to fair trading provisions (Telford, 1999).

Area	Sub-component	Specifics
	False representation of goods or services	A utility must be aware that it is an offence under fair trading provisions to falsely represent that goods are of a particular standard, quality or composition1. It is possible that the user of a water product will ask for a guarantee of quality from the utility as part of its own quality assurance program. In Australia, similar elements apply to "fit for purpose" requirements under the defective goods provision of the TPA which is a form of statutory protection of customer contracts2 .
	Defective goods	
Statutory liability	Breach of statutory obligations	The utility and user of the water will have to ensure cognisance of and compliance with obligations in relation to health and the environment and their associated regulations and guidelines. Often, statutes provide persons with standing3 that they would not otherwise be entitled to under common law, and hence can widen the circumstances under which a utility may face legal proceedings.
	Statutory incorporation of guidelines	Many of the metropolitan water utilities in Australian, including Sydney, Melbourne and Perth, have licences that tie them to guidelines (NHMRC/ARMCANZ, 1996) that were designed to be of a voluntary non-legal nature (McKay and Moller, 2000). In this case, failure to meet these guidelines may bring with it statutory liabilities.
	Statutory immunity	Legislation under which water authorities are constituted and their functions defined may also provide for circumstances in which the authority has been granted an exclusion of liability. However, the Australian High Court4 has narrowly read these provisions such that they do not extend to the normal commercial functions of the Authority, but only to the exercise of the specific functions or powers authorised by the legislation (Bartley, undated). Government utilities subject to corporatisation and privatisation are increasingly being treated by Australian courts as like private entities, especially where they conduct business activities also conducted by the private sector.

Common law

Common law is derived from precedent established by court judgements. It is traditionally associated with private property rights and has arisen as a result of civil (as opposed to criminal) actions. Justice in these actions is generally sought in the form of damages e.g. a monetary redress. Common law has historically had two main functions:

- To enforce the right to exclude others from the benefit or use of private property; and
- To prevent the use of private property by one owner from having a detrimental impact on the ability of neighbouring private property owners to use their property.

To protect these rights, the courts developed the laws of trespass, nuisance and negligence. Each of these elements forms part of the law of torts ("wrongs"). Through court application, these laws have evolved and been applied to a variety of circumstances including

1 *Trade Practices Act 1974* (Cth) s 75AZC, False or misleading representations, ss (1).

2 *Trade Practices Act 1974* (Cth) PART VA

3 *Trade Practices Act 1974* (Cth), s 80.

4 *Water Administration Act 1986* (NSW), which was recently repealed by the *Water Management Act 2000*

(NSW) and hence a different set of immunity provisions, was the subject of interpretation in *Puntoriero and Anor v The Water Administration Ministerial Corporation* (1999 Australian Torts Reports, 81, 520). Although the particular legislation is not in force, the principles established can generally be applied.

2.2 STRUCTURE OF THE BOOK

The remaining chapters in the book detail the steps required to set up and implement a water safety plan, whatever the size of the system or its location. Small supplies are dealt with in their own chapter (13) and a number of model water safety plans are outlined in the appendix. The material is illustrated using a number of examples and two case studies, which provide examples of each of the key steps.

In most cases water safety plans will be set up and implemented for existing systems, however, there are also chapters covering the upgrading of existing systems and also the development of water safety plans for new supplies.

3

Organising the development of water safety plans

This chapter outlines the initial steps in the development of a water safety plan, including commitment to the approach, setting up a water safety plan team and the description of the intended use of the water.

3.1 COMMITMENT TO THE WATER SAFETY PLAN APPROACH

While many drinking-water supplies provide adequate and safe drinking-water in the absence of a water safety plan, the formal adoption of a water safety plan and associated commitment to the approach can have a number of benefits. Major benefits of developing and implementing a water safety plan for these supplies include the systematic and detailed assessment and prioritisation of hazards and the operational monitoring of barriers or control measures. In addition, it provides for an organized and structured system to minimize the chance of failure through oversight or lapse of management. This process increases the consistency with which safe water is supplied and provides contingency plans to respond to system failures or unforeseeable hazardous events.

For the successful implementation of the water safety plan, management commitment is vital. There are a number of features of water safety plan adoption and implementation that can be attractive to management, including:

- water safety plans represent an approach that demonstrates to the public, health bodies and regulators that the water supplier is applying best practice to secure water safety;
- the benefits that arise from delivering a more consistent water quality and safety through quality assurance systems;
- avoidance of the limitations associated with relying on end-product testing as a means of water safety control;
- potential savings as a result of adopting the water safety plan approach (see Chapter 15);
- potential for significant improvements in asset management; and
- potential for marketing of services, to new and existing customers, of an improved product.

Implementation of a pilot water safety plan project, alongside existing water quality management approaches, as a means of demonstrating the feasibility and advantages of the approach may facilitate acceptance of the method.

3.2 DEVELOPMENT OF A WATER SAFETY PLAN

As outlined in section 1.4 a water safety plan essentially consists of three components;

- system assessment;
- operational monitoring; and
- management plans, documentation and communication.

In developing a water safety plan these can be broken down into a series of steps as shown in Figure 3.1, with the relevant chapter number shown in brackets next to each individual step. This chapter details the first of these steps (i.e., assembling the team). It is important to note, however, that this is not a one-off process but is iterative and progressive as illustrated in Figure 3.1.

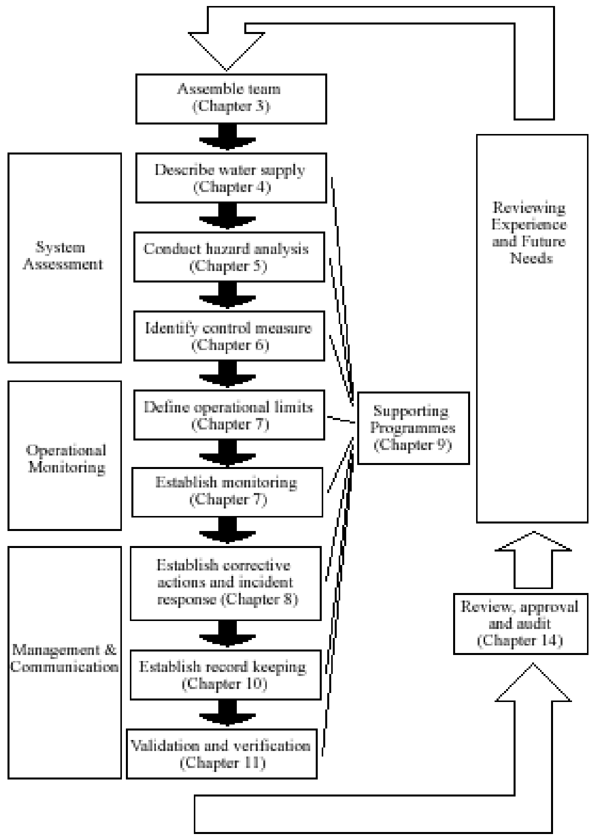


Figure 3.1: Steps in the development of a water safety plan

3.3 ASSEMBLE THE WATER SAFETY PLAN TEAM

The preliminary step is to assemble a team to develop the water safety plan. For large supplies, a multi-disciplinary team of key people should be assembled to develop the plan. This should include managers, engineers (operations, maintenance, design, capital investment), water quality controllers (microbiologists and chemists) and technical staff involved in day-to-day operations. All members of the team should have a good knowledge of the system. As discussed in Chapter 13, water safety plans for small supplies may be developed generically rather than for individual supplies.

A team leader should be appointed to drive the project and ensure focus. The team leader should have the authority, organisational and interpersonal skills to ensure the project can be implemented. In situations where required skills are unavailable locally, the team leader should explore opportunities for external support. This can include benchmarking or partnering arrangements with other organisations, national or international assistance programmes and internet resources.

It is the team's responsibility to define the scope of the water safety plan. The scope should describe which part of the water supply chain is involved and the general classes of hazards to be addressed.

The team should develop each step of the water safety plan in accordance with the steps outlined in Figure 3.1. Other desirable features of the water safety plan team include:

- knowledge of the water supply system and the types of drinking-water safety hazards to be anticipated;
- authority to implement any necessary changes to ensure that safe water is produced;
- inclusion of people who are directly involved with the daily operations; and
- having sufficient people on the team to allow for a multi-disciplinary approach, but not so many that the team has difficulty in making decisions. Team numbers will vary according to the size of the organisation and complexity of process. The use of sub-teams is common and might for example include, water harvesting, water treatment and distribution operations.

The membership of the team should be periodically reviewed with new or replacement members brought in if required. Table 3.1 illustrates the activities and responsibilities associated with development of a water safety plan in a developing country.

Table 3.1: Activity / responsibility matrix (Godfrey *et al*.2003)

		NWSC				
Activity	Responsible	WQCD	HQ	OSUL	MAK	WEDC
System Assessment						
Identification and printing of maps	Senior ngineer	I	A	R	I	A
Field work	Engineers	I	A	I	R	A
Reporting and data analysis	Engineers	I	A	I	R	I
Transport arrangements	Principal Analyst	R	A	A	A	I
Management of logistics	Principal Analyst	R	A	A	A	I
Coordination	Principal Analyst	R	A	I	I	I
Water Quality Assessment						
Laboratory analysis	Principal Analyst	R	A	A	I	I
Sampling	Principal Analyst	R	A	A	I	I
Transport	Principal Analyst	R	A	A	A	A
Coordination	Principal Analyst	R	A	I	I	I
Report and data analysis	Principal Analyst/ Quality control manager	R	A	I	I	I

Activity	Responsible	NWSC WQCD	NWSC HQ	OSUL	MAK	WEDC
Logistics	Principal Analyst	R	A	A	I	I
Training for WQ analysis	Consultant	I	A	A	I	R
WQ assessment preparation	Consultant	I	A	I	I	R

R - Responsibility, I - Involved, A - Aware
NWSC – National Water and Sewerage Corporation (the utility responsible for the production and distribution of piped water)
WQCD – Water Quality Control Department of NWSC
HQ – NWSC head quarters
OSUL – Ondea Services Uganda Limited (responsible for operating the distribution system)
MAK – Makerere University
WEDC – Water, Engineering and Development Centre (Loughborough University)

3.4 INTENDED WATER USE

For general purposes, water safety plans will apply to domestic potable use of drinking-water. The expected use of the product should, however, be determined and documented by the water safety plan team. Factors that need to be considered include:

- what consumer education is in place for water use and how is this communicated, including how consumers are notified of potential contamination?
- who is the water intended for and what is its intended use?
- what special considerations are in place for vulnerable groups such as infants, hospitalised patients, dialysis patients, the elderly and immuno-compromised? Are there any groups for whom the water is specifically not intended?
- the numbers of people served by different service levels (communal, yard, within-house – see Tables 3.2 and 3.3); and
- socio-economic status of different communities served.

This information is important, as it will be used in the hazard analysis to determine the hazard potential of the water.

Table 3.2: Summary of requirement for water service level to promote health (from Howard and Bartram 2003)

Service level	Access measure	Needs met	Level of health concern
No access (quantity collected often below 5 l/c/d)	More than 1000 m or 30 minutes total collection time	Consumption – cannot be assured Hygiene – not possible (unless practised at source)	Very high
Basic access (average quantity unlikely to exceed 20 l/c/d)	Between 100 and 1000 m or 5 to 30 minutes total collection time	Consumption – should be assured Hygiene – handwashing and basic food hygiene possible; laundry/bathing difficult to assure unless carried out at source	High

Intermediate access (average quantity about 50 l/c/d)	Water delivered through one tap on-plot (or within 100 m or 5 minutes total collection time	Consumption – assured Hygiene – all basic personal and food hygiene assured; laundry and bathing should also be assured	Low
Optimal access (average quantity 100 l/c/d and above)	Water supplied through multiple taps continuously	Consumption – all needs met Hygiene – all needs should be met	Very low

Table 3.3: Water supply access data for 1990 and 2000 by no access, access to improved sources and piped supply (from WHO and UNICEF 2000)

Year	No access (millions)	Access to improved sources within 1 kilometre (millions)	Access through household connections (millions)
1990	23% (1203)	77% (4060)	48% (2549)
2000	17% (1074)	83% (5150)	52% (3232)

An example description of an intended use is provided in Box 3.1. This description provides the team with further understanding of the nature of the population served and any particular characteristics that may increase vulnerability to waterborne disease.

Box 3.1. Example 'intended use' description

Example 1
Water utility X provides water to the general population.
The water supplied is intended for general consumption by ingestion. Dermal exposure to waterborne hazards through washing of bodies and clothes, and inhalation from showering and boiling are also routes for waterborne hazards.
Foodstuffs may be prepared with the water.
The intended consumers do not include those who are significantly immunocompromised or industries with special water quality needs. These groups are advised to provide additional point-of-use treatment.

Example 2
Utility Y provides water to approximately half the population.
The water is intended for general consumption by ingestion. Dermal exposure to waterborne hazards through washing of bodies and clothes, and inhalation from showering and boiling are also routes for waterborne hazards.
Foodstuffs may be prepared from the water and market sellers use the water for freshening produce.
About half the population served rely of water supplied from public taps, with a further significant proportion relying on tanker services filled from hydrants.
The socio-economic level of the population served by public taps is low and vulnerability to poor health is consequently high.
A significant proportion of the population is HIV positive, which increases vulnerability further.

3.5 CASE STUDIES

Two cases studies are presented below, one outlining a water safety plan from a water utility in a developed country (Melbourne Water, Australia) and one from a developing country (Uganda). Elements drawn from each of these are presented in each chapter in order to illustrate the various steps in the water safety plan process. In addition, the water safety plan for selected elements of the Gold Coast Water system is shown in Appendix A.

3.5.1 Melbourne Water case study

Melbourne Water is located in Victoria, Australia and was the first bulk water supplier in Australia to implement and achieve HACCP certification. The case study examples presented have been drawn from Melbourne Water's Drinking-Water Quality Management System (adapted slightly to the water safety plan methodology).

3.5.1.1 Intended use

Water supplied by Melbourne Water to the retail water companies must meet the customer and product specific requirements defined in the Bulk Water Supply Agreement The Agreement defines the water quality targets to be achieved at interfaces with the retail company (refer to the finished product specifications, section 3.5.1.2).

The water quality risk issues must also be managed consistent with the intended use of the product supplied to end-users by the retail water companies. That is:

- for immediate consumption by the general public, with no further treatment or boiling by the consumer;
- for other domestic and commercial uses;
- meeting the water quality requirements of the Retail Company licences; and
- considering the latest developments in drinking-water quality research and Australian best practice for operating water supply systems.

The Australian Drinking Water Guidelines, developed through the Australian National Health and Medical Research Council), are based on the WHO Guidelines. Supply-by-agreement services provided to retail company customers directly from Melbourne Water's infrastructure have no guarantee of water quality or quantity. These supplies are not intended for drinking or domestic uses where the water may be ingested.

3.5.1.2 Finished product specifications

As defined in the Bulk Water Supply Agreement (BSWA) for:

- Effective chlorination: Chlorine contact time (CT) ≥ 15 mg/l.min. Standards and action levels for water quality parameters including total coliforms.
- Monitoring Point (annual performance)
- E.coli: 99% of samples <1 org/100mL
- Trihalomethanes: all samples ≤ 0.15 mg/L
- Monochloroacetic acid: all samples ≤ 0.15 mg/L
- Dichloroacetic acid: all samples ≤ 0.10 mg/L
- Trichloroacetic acid: all samples ≤ 0.10 mg?l

95% upper confidence limit on the mean:

Turbidity

Apparent Colour pH

Limits for these three criteria based on historical erformance and set within the aesthetic guidelines specified in the Australian Drinking Water Guidelines.

Iron	≤ 0.15 mg/l
Manganese	≤ 0.05 mg/l
Aluminium (acid soluble)	≤ 0.1 mg/L

The above BWSA specifications for water quality are set to enable the retail water companies to meet their licence requirements for water quality and deliver a safe, aesthetically acceptable product with their current operating systems for managing detention times and product quality. Other parameters, including chemical residues, should meet the specifications of the Australian Drinking Water Guidelines, where limits for drinking-water are defined.

Procedures for responding to failure of these specifications are documented in the BWSA and Melbourne Water's standard operating procedure for Microbiological Water Quality Monitoring Exceedence.

3.5.1.3 Team

Multi-disciplinary teams were formed to develop the company (Hazard Analysis Critical Control Point) HACCP (Water Safety) plan and comprised members from Melbourne Water and representatives from the three retail water companies (City West Water, South East Water and Yarra Valley Water) supplied by Melbourne Water. Team members (outlined in Table 3.4) participated in a one-day training course, and the plan was derived during a series of workshops.

Table 3.4: Team members

Job title	Work team	Expertise
Team Leader Senior Engineer	Water Quality Planning	Water Quality Engineering
Water Supply Operator	Water Harvesting Team	Operations – Upper Yarra Reservoir
Process Support – Service Delivery	Operations – North Area	Water Treatment Specialist
Water Supply Operator	Westernport Area Team	Operations – distribution/treatment
Section Leader Water Treatment	Treatment Systems	Treatment plant asset management
Operations Contractor	Operations – South Area	Water supply engineering
Water Supply Operator	Thomson Reservoir Team	Operations – Thomson Reservoir
Process Engineer	Operations – North Area	Water supply engineering
Water Supply Operator	Silvan Reservoir Team	Treatment plant operations
Water Supply Operator	Maroondah-Winneke Reservoir team	Sugarloaf Reservoir, Winneke Treatment Plant and Maroondah Reservoir area
Principal Scientist	Water Quality Planning	Microbiology
Section Leader Headworks	Operations	Catchment operations
Scientist from retail water company	Retail Water Company	Water quality specialist/chemist
Engineer from retail water company	Retail Water Company	Water quality engineering (distribution)
Engineering manager from retail water company	Retail Water Company	Water quality planning

3.5.2 Kampala case study

This is largely taken from Godfrey *et al*. 2003. Kampala is the capital city of Uganda in East Africa. The piped water supply is managed by the National Water and Sewerage Corporation (NWSC) with distribution operation let by management contract to Ondeo Services Uganda Limited (OSUL). Kampala was the first water supplier in Africa to develop a water safety plan, which was achieved with technical assistance from the Water, Engineering and Development Centre (WEDC) UK and funding from the Department for International Development (DFID) UK through their Knowledge and Research programme.

3.5.2.1 Intended use

Water supplied by NWSC Kampala supply must meet the Uganda national standards for drinking-water that were set based the WHO *Guidelines for Drinking-Water Quality, 2nd edition* (1993). Furthermore, the national statute that covers NWSC operations requires that NWSC should ensure that the water supplied is potable and safe to drink by the general public without further need for treatment or boiling by the consumer and for all other registered commercial and industrial users.

3.5.2.2 Team

A multi-disciplinary team was formed to develop the water safety plan and risk maps of the distribution system. This included representatives from NWSC, OSUL, Makerere University Public Health and Environmental Engineering laboratory and WEDC. Team members (outlined in Table 3.5) participated in a series of workshops and field activities to develop the water safety plan.

Table 3.5: Team members

Job title	Work team	Expertise
Water Quality Control Manager	Water Quality Control	Water quality analysis and control
Principal Analyst	Water Quality Control	Water quality analysis and control
Chief Engineer Planning and Capital Development (NWSC)	Planning and Capital Development	Water engineer
Manager Operations (NWSC)	Operations	Water engineer
Senior Engineer (OSUL)	Distribution management	Water engineer
Analysts (NWSC)	Water quality control	Water quality analysis
Gaba treatment works manager	Water production	Water treatment engineer
Engineers (OSUL)	Distribution management	Water engineers
Manager GIS (NWSC)	Information management and mapping	GIS and mapping
Lecturer Makerere University	Public Health and Environmental Engineering	Environmental engineer
Analyst Makerere University	Public Health and Environmental Engineering	Water quality analysis
Assistant Programme Manager (WEDC)	Water, Engineering and Development Centre (UK)	Water engineer
Programme Manager (WEDC)	Water, Engineering and Development Centre (UK)	Water quality management and monitoring
Senior Research Fellow	Robens Centre for Public and Environmental Health	Water quality analysis and monitoring

NWSC – National Water and Sewerage Corporation
OSUL – Ondeo Services Uganda Limited
WEDC – Water, Engineering and Development Centre

4

Water supply description

A description of the drinking-water system is equally applicable to large utilities with piped distribution systems, piped and non-piped community supplies, including handpumps and individual domestic supplies. Assessment can be of existing infrastructure or of plans for new or upgrading of supplies (see Chapter 12). As drinking-water quality varies throughout the system, the assessment should aim to determine whether the final quality of water delivered to the consumer will routinely meet established health-based targets (see section 1.4.1).

Water safety plans should, by preference, be developed for individual water supplies, except for very small systems where this may not be realistic (see Chapter 13), in which case a 'model' water safety plan based upon the relevant technology may be most appropriate (see Appendix A).

4.1 DESCRIBE THE WATER SUPPLY

The first step in the system assessment process is to fully describe the water supply. This should cover the whole system from the source to the point of supply, covering the various types of source water, treatment processes and so on. Box 4.1 outlines examples of information to be considered in describing the water supply.

Catchments

- Geology and hydrology
- Meteorology and weather patterns
- General catchment and river health
- Wildlife
- Competing water uses
- Nature and intensity of development and land-use
- Other activities in the catchment which potentially release contaminants into source water
- Planned future activities

Surface water

- Description of water body type (e.g. river, reservoir, dam)
- Physical characteristics such as size, depth, thermal stratification, altitude
- Flow and reliability of source water
- Retention times
- Water constituents (physical, chemical, microbial):
- Protection (e.g. enclosures, access)
- Recreational and other human activity
- Bulk water transport

Groundwater systems

- Confined or unconfined aquifer
- Aquifer hydrogeology
- Flow rate and direction
- Dilution characteristics
- Recharge area
- Well-head protection
- Depth of casing
- Bulk water transport

Box 4.1: Examples of information useful to describe a water supply - continued

Treatment systems

- Treatment processes (including optional processes)
- Equipment design
- Monitoring equipment and automation
- Water treatment chemicals used
- Treatment efficiencies
- Disinfection removals of pathogens
- Disinfection resi dual / contact period time

Service reservoirs and distribution systems

- Reservoir design
- Retention times
- Seasonal variations
- Protection (e.g. covers, enclosures, access)
- Distribution system design
- Hydraulic conditions (e.g. water age, pressures, flows)
- Backflow protection
- Disinfectant residuals

Two brief supply description examples are shown in Box 4.2. These descriptions provide the water safety plan team with an overview of the supply and an initial understanding of existing controls.

Box 4.2: Example supply description (Godfrey *et al*. 2003)

Example 1
Water utility X's objective is to produce potable water.
The water is received from a bulk water supplier and delivered to customers to meet the water quality objectives set by the Health Authority according to public health targets.
The water quality objectives are captured in the Operating Licence, Customer Contract and the current and relevant drinking-water Guidelines.
Disinfection and fluoridation chemicals are supplied by ABC chemical manufacturer and form part of the delivered product. Quality agreements are in place in relation to treatment chemicals received from manufacturers and bulk water received.

Example 2
Water utility Y's objective is to produce, potable water for a town and a series of small communities.
Water is obtained from two surface water reservoirs, which are located 35 and 20 km from the town.
Both reservoirs have protected areas, but encroachment is a serious problem at one reservoir, which is also subject to pollution from small-scale industry.
The treatment works at each reservoir has a conventional configuration of coagulation-flocculation-settling, rapid sand filtration and terminal chlorination is used for disinfection.
The water from both reservoirs flows to a high-level and a low-level service reservoir. There are connections directly onto both transmission mains serving intermediate settlements.

4.2 CONSTRUCT FLOW DIAGRAM

Hazard identification (which will be considered more fully in Chapter 5) is facilitated through the conceptualisation of the specific water supply system, through the construction of a flow diagram. A generalised flow diagram for a drinking-water supply is shown in Figure 4.1.

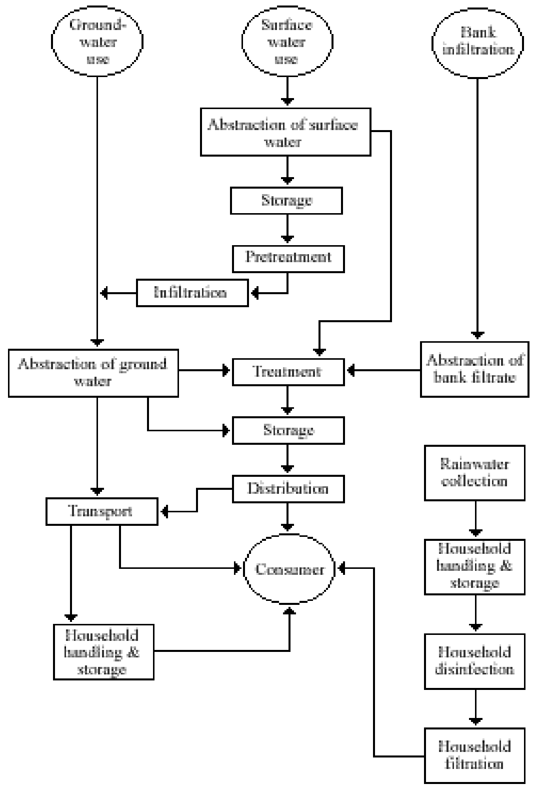


Figure 4.1 Generic system flow diagram (adapted from Havelaar 1994)

To enable hazards to be clearly identified, system-specific flow charts are required that elaborate on the processes involved at each step (Figure 4.2). Typically, this is done through the use of sub-ordinate flow charts and maps. For some water supplies the treatment step may only consist of chlorination, while for others there may be many steps including conventional treatment. Similarly, for some supplies there is little that can be done to influence catchments and source waters. For others, good access to catchment and source water information exists. This may be combined with the potential to influence catchment activities and/or undertake selective transfer and withdrawal of water. In such cases extensive catchment and source water information could be part of the flow chart or system map since catchment and source water control measures will be incorporated within the plan.

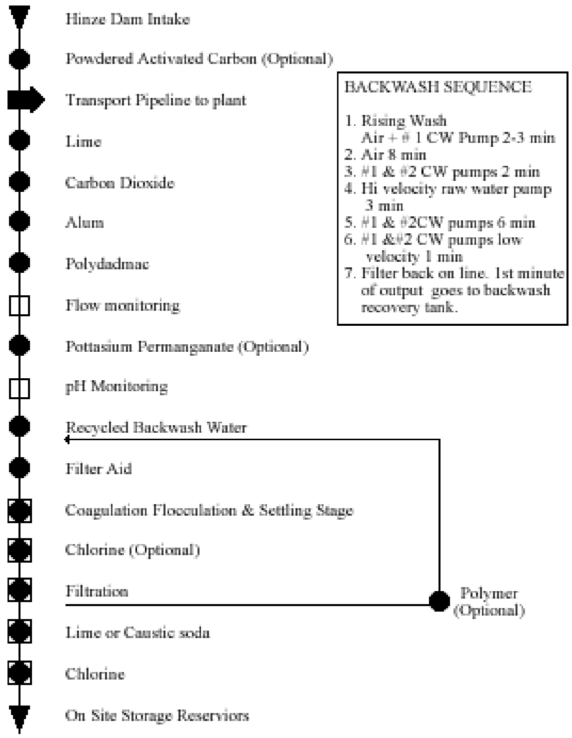


Figure 4.2: Flow chart for the Gold Coast Water (Australia) Molendinar water purification plant (clarifier model)

4.3 CONFIRMATION OF FLOW DIAGRAM

It is essential that the representation of the system is conceptually accurate, as the water safety plan team will use this as the basis for the hazard analysis. If the flow diagram is not correct, the team may miss significant hazards and not consider appropriate control measures.

To ensure accuracy, the water safety plan team validates the completeness and accuracy of the flow diagram. A common method of validating a flow diagram is to visit the system and check the set up of the system and processes.

Proof of flow chart validation should be recorded along with accountability. For example, a member of the water safety plan team may sign and date a validated flow chart as being accurate and complete.

4.4 MELBOURNE WATER CASE STUDY – ABBREVIATED SUPPLY DESCRIPTION

Melbourne Water harvests 90% of its water from more than 160,000 hectares of uninhabited, forested catchment with no public access, urban development or agriculture (catchments are shown in Figure 4.3).

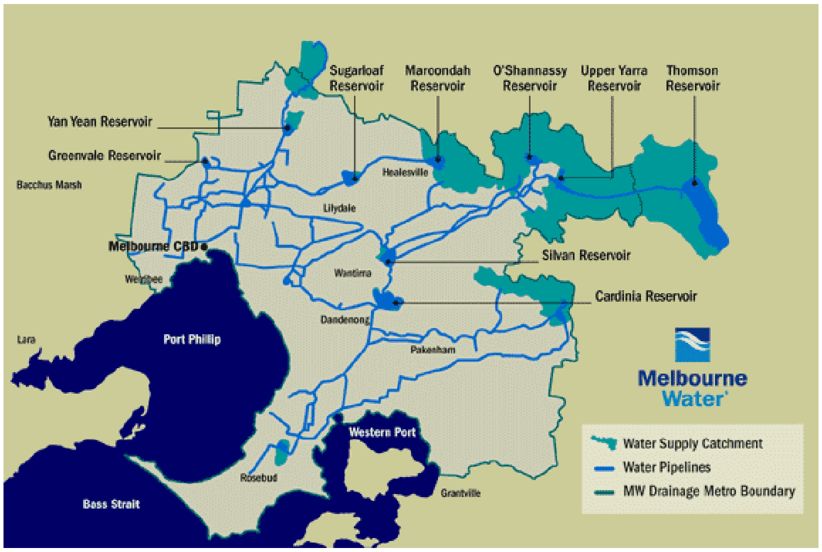


Figure 4.3: Water supply system (MW 2003)

Water is stored in a number of large reservoirs (40,000 ML to 1,000,000 ML) before treatment by disinfection only prior to distribution. The 10% of Melbourne Water's supply that is drawn from agricultural catchments is fully treated (convention filtration or membrane filtration) before distribution.

Melbourne Water is a State Government-owned utility and is the wholesale water supplier for the city of Melbourne (approximately 3.5 million people). Melbourne Water is responsible for harvesting and treatment of drinking-water. Drinking-water is distributed to consumers by three retail water companies, which operate under licences issued by the State Government. These licences specify standards of water supply for Melbourne consumers. Melbourne Water's water supply obligations to the retail companies are defined in a formal contract called the Bulk Water Supply Agreement (BWSA).

Melbourne Water manages the harvesting of water from catchments, the major transfer, storage and treatment of water and the transfer of water to numerous interface points with the retail companies. It operates, manages and plans Melbourne Water's water supply system which comprises:

- 156,756 hectares of catchments and headworks;
- 11 major storage reservoirs: 9 currently in use with 1,773GL capacity;

- 59 service reservoirs: 41 steel tanks, 5 concrete tanks and 13 earthen basins;
- 1,029 km of distribution mains;
- 225.5km of aqueducts, siphons and tunnels;
- 18 pump stations;
- 5 filtration plants;
- 46 disinfection plants: 42 chlorine and 4 ultra violet;
- 8 fluoridation plants;
- 13 pH correction plants;
- 2 hydro power stations;
- 19 valve complexes;
- 78 pressure reducing stations and flow control valves;
- 23 weirs;
- 78 billing flow meters;
- 46 hydrographic monitoring stations (streamflow and rainfall); and
- 14 aqueduct and reservoir cut-off (catch) drains.

A simplified process flow chart for the Silvan system is shown in Figure 4.4.

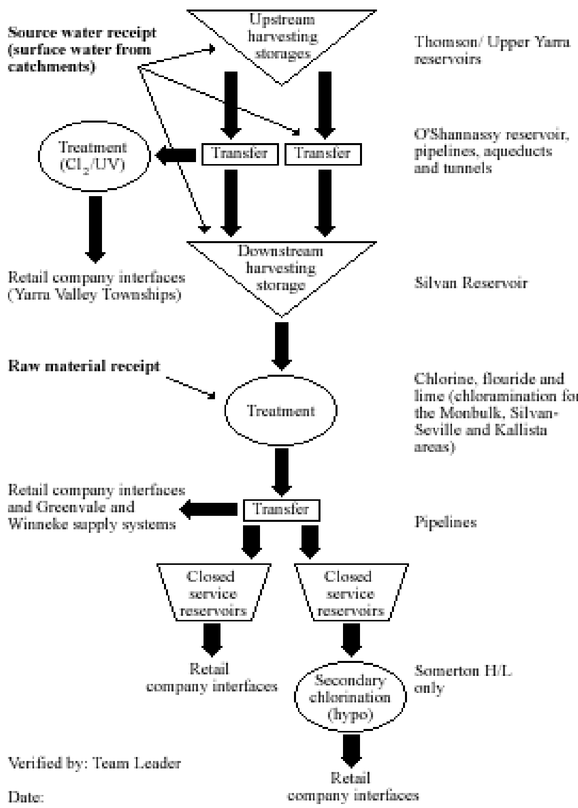


Figure 4.4: Simplified Process Flow Chart – Silvan System (adapted from MW 2003)

4.5 KAMPALA CASE STUDY – ABBREVIATED SUPPLY DESCRIPTION

The Kampala system takes its water from the mouth of the Inner Murchison Bay on Lake Victoria, the second largest inland water body in the world. The catchment of the Inner Murchison Bay includes Kampala and receives contaminated water from the urban drainage system which, because of low sanitation coverage, contains significant faecal material. The original extensive wetlands that fed into the Inner Murchison Bay and which provided some removal of contaminants are becoming rapidly degraded. The wastewater treatment works at Bugolobi discharges into the Inner Murchison Bay and there is growing industrial and commercial development with associated discharges. The catchment also includes agricultural land and local fishing.

The Kampala system has two treatment works at Gaba that utilise conventional treatment processes. The average combined capacity of the works is 95,000m^3/day, which is then distributed to 5 major service reservoirs. There are two distinct pressure zones (high and low) in the supply. The principal service reservoir for the low pressure transmission main is located in the city centre at Gun Hill. The high-pressure transmission mains supplies balancing tanks at Muyenga, South of the City. The Muyenga tanks serve some secondary transmission mains directly and also supplies three other service reservoirs located in the North (Naguru), East (Mutungo) and West (Rubaga) respectively. The entire network covers more than 871 kilometres of pipeline with over 40,000 household connections. Based on previous assessments of numbers of people served with household connections and of water source use by households without a household connection, it is estimated that the network serves 700,000 people.

Figure 4.5 below provides a schematic diagram for the Kampala system.

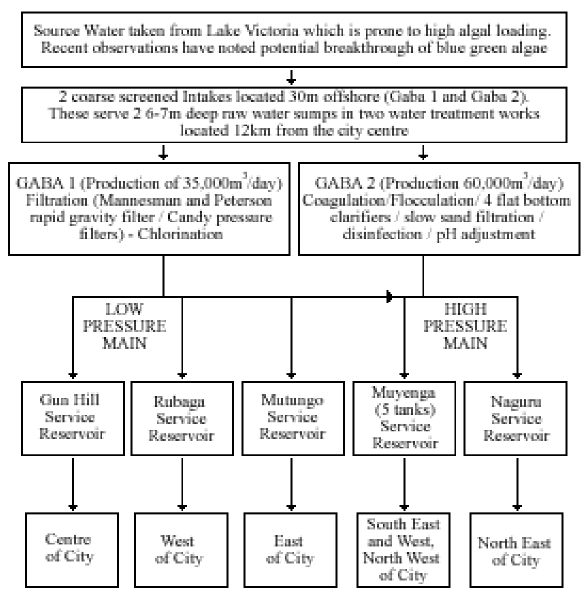


Figure 4.5: Flow diagram for the Kampala network (taken from Godfrey *et al*. 2003).

5

Understanding the hazards and threats

Having described the water supply and produced flow diagrams in order to represent the supply in a logical and easily understood way, the next step is to conduct a hazard analysis in order to establish what requires controlling in order to provide safe drinking-water.

5.1 HAZARD IDENTIFICATION

Hazards may occur or be introduced throughout the water system, from catchment to consumer. Effective risk management, therefore, requires identification of all potential hazards, their sources, possible hazardous events and an assessment of the risk presented by each.

> A hazard is any biological, chemical, physical or radiological agent that has the potential to cause harm.
>
> A hazardous event is an incident or situation that can lead to the presence of a hazard (what can happen and how).
>
> Risk is the likelihood of identified hazards causing harm in exposed populations in a specified timeframe, including the magnitude of that harm and/or the consequences.

The hazard identification step, therefore, requires the water safety plan team to consider all potential biological, physical, chemical and radiological hazards that could be associated with the water supply. The team should start with the water sources, then progress through the validated flow diagram. At each step the objective is to:

identify what could happen to lead to contamination; and

the associated control measures for

each hazard.

The water safety plan team should also consider influencing factors such as:

- variations due to weather;
- accidental or deliberate contamination;
- pollution source control practices;
- wastewater treatment processes;
- drinking-water treatment processes;
- receiving and storage practices;
- sanitation and hygiene;
- distribution maintenance and protection practices; and
- intended consumer use (see section 3.4).

5.1.1 Biological hazards

These hazards include frank and opportunistic pathogens such as:

- bacteria;
- viruses;
- protozoa; and
- helminths

Other, non-pathogenic organisms that influence the acceptability of drinking-water should also be considered. These include *Asellus* and *Cyclops.*

It is not necessary or practical to completely eliminate microorganisms from drinking-water supply systems. What is required is to keep numbers of pathogens below levels determined to represent an acceptable level of risk as outlined in the water quality targets (see section 1.4.1).

Pathogens in water supply systems generally originate from human or animal faecal material contaminating raw water or that finds its way into the water supply delivery system. Common sources of faeces include wildlife such as birds, grazing animals and vermin in and around reservoirs, backflow from unprotected connections and sewer cross connections (Clark *et al*. 1993).

5.1.2 Chemical hazards

A chemical hazard can be considered as any chemical agent that may compromise water safety or suitability, as shown in Table 5.1.

Table 5.1: Examples of chemical hazards that may occur in drinking-water supply systems.

Chemicals from watershed/ catchment	Chemicals from reservoir storage	Chemicals from water treatment processes	Chemicals from distribution
Nitrate	Algal toxins	Flocculants	Copper
Arsenic	Cleaners	pH adjusters	Lead
Fluoride	Liner chemicals	Disinfection by-products	Cleaners
Pesticides	Lubricants		Petroleum

Chemicals from watershed/ catchment	Chemicals from reservoir storage	Chemicals from water treatment processes	Chemicals from distribution
Other heavy metals Organic toxicants Herbicides Rodenticides	Pesticides Herbicides	Impurities in treatment chemicals	products Liner chemicals

5.1.3 Physical hazards

Physical hazards may affect water safety by posing a direct risk to health (e.g. through choking), through reducing the effectiveness of treatment and in particular residual disinfectants or because consumers find the water unacceptable and use alternative, more contaminated water sources. The most common physical hazard in water is sediment within the water supply. Sediments and particulates can also include pipe materials, pipe liner materials, sloughed biofilms or iron and manganese films. Suspended or resuspended sediments can contain toxic chemicals or can have pathogens attached and can co-transport other hazards.

5.1.4 Radiological hazards

Radiological contamination of drinking-water generally occurs as a result of contamination by man-made sources of radiation. Contamination can arise from:

- naturally occurring radioactive species in drinking-water sources;
- the contamination of water from the mining industry; and
- radionuclides from the medical or industrial use of radioactive materials.

5.2 HAZARDOUS EVENTS

Once hazards are listed it is important to consider the corresponding events that lead to their entry into the drinking-water supply. These might be termed hazardous events or hazard causes.

Hazardous events can cause contamination directly and indirectly. For example, pathogens can enter water supplies directly from faeces. However, cyanobacterial toxins result from growth of toxigenic cyanobacteria which are in turn promoted by a combination of factors. Therefore, factors, such as nutrients, which can promote cyanobacterial proliferation, can lead to water becoming unsafe and should be considered as contributory factors leading to the presence of a hazard. These contributory factors require managing as part of the water safety plan. Box 5.1 illustrates how hazardous events in the catchment could be identified through performing a sanitary survey.

Box 5.1: Identifying hazardous events in the catchment – performing a sanitary survey

A sanitary survey of the catchment area, the integrity of the infrastructure of the source headworks and the distribution system should be undertaken. Standardised forms for sanitary surveys and inspections are available in a number of documents linked to the WHO Guidelines for Drinking-water Quality (WHO, 1997; Howard, 2002) and are shown in Appendix C.

When performing a sanitary survey it is important to ensure that pollutant source-pathway-receptor relationships are borne in mind. Hazards in the environment do not automatically pose a risk to a water supply if there is no pathway by which they can enter the water supply. This is of particular importance for groundwater sources, where the hydrogeological environment and vulnerability of aquifers must be taken into account to ensure that a realistic assessment can be made of the likelihood of contamination and its severity. In particular the potential for reduction in pathogen densities and chemical concentrations through attenuation, die-off and dilution should be assessed. Further details are provided in the monograph on the Protection of Groundwater for Public Health (Schmoll *et al*. 2004). The sanitary survey of water sources should result in a map that provides an indication of the location of major hazards and an indication of the likely risk posed.

For distribution systems, the situation is somewhat different, as the primary purpose is the prevention of contamination being introduced or regrowth in the pipes. In distribution systems, an example of a hazard-pathway-receptor relationship is a pipe running at low pressure within a soil saturated with contaminated surface water derived from a leaking sewer above the main. There are many permutations in this scenario when risk is actually low. For instance, although intermittence means that water is not received by the household, it does not mean that there is no water in the pipe, usually the reverse is true, simply the pressure is too low to ensure water can be delivered through the tap. Even if there is contaminated water in the soil, if the moisture content is low even the small amount of water in the pipe may be sufficient to ensure the hydraulic gradient is from the pipe to the soil and not vice versa. This does not mean that the repair of the pipe is not needed, but if there are several parts of the system where the same set of hazards and vulnerability occur, then priority should be given to the point when, commonly, the hydraulic gradient would be from the soil to pipe. This requires that some estimation be made of the vulnerability of the supply to contamination is taken into account (for further details see the monograph on Piped Distribution Systems published by WHO; Ainsworth 2004).

5.3 PRIORITISING HAZARDS

The control measures (see Chapter 6) needed and the frequency of monitoring should reflect the likelihood and consequences of loss of control. In any system, there may be very many hazards and potentially a large number of control measures. It is therefore important to rank the hazards in order to establish priorities.

Simple risk assessment matrices are available and have been successfully applied to prioritising hazards in the water industry (e.g. Gray and Morain 2000; Deere *et al*.

2001). These typically apply technical information from guidelines, scientific literature and industry practice with well informed expert judgement supported by third-party peer review or comparison against other systems (benchmarking). Benchmarking differs from other quality improvement techniques in that its focus is on identifying what the external best practices are for key business functions and processes and has been defined as:

> "A method for facilitating continuous improvement by systematically comparing one's own processes, practices and performance against the best practice of others with a view to adopting, adapting or enhancing that practice to one's own situation" (NSW DLWC and LGSA NSW, 1997).

An important consideration is that the risk ranking is specific for each water supply system since each system is unique.

5.3.1 Prioritisation matrix

By using a semi-quantitative risk assessment, the water safety plan team can calculate a priority score, for each identified hazard. The objective of the prioritisation matrix is to rank hazardous events to provide a focus on the most significant hazards. The risk posed by individual hazards does not need to be quantified. There are a number of approaches to ranking risk. The water safety plan team needs to determine which approach it will use.

The likelihood and severity can be derived from the water safety plan team's technical knowledge and expertise, historical data and relevant guidelines. An example of descriptors that can be used to rate the likelihood and severity or impact for calculation of the risk score is given in Table 5.1 and a qualitative risk analysis matrix in Table 5.2.

Table 5.1: Example of definitions for likelihood and consequence/impact categories that could be used in hazard prioritisation

Level	Descriptor	Description
Likelihood		
A	Almost certain	Once a day
B	Likely	Once per week
C	Moderate	Once per month
D	Unlikely	Once per year
E	Rare	Once every 5 years
Consequence/impact		
1	Insignificant	No detectable impact
2	Minor	Minor aesthetic impact causing dissatisfaction but not likely to lead to use of alternative less safe sources
3	Moderate	Major aesthetic impact possibly resulting in use of alternative but unsafe water sources
4	Major	Morbidity expected from consuming water
5	Catastrophic	Mortality expected from consuming water

Note: Measures used should reflect the needs and nature of the organization and activity under study

Whatever method is applied, the water safety team needs to determine a cut off point above which all hazards will be retained for further consideration. There is little value in expending a great deal of effort considering very small risks.

Table 5.2: Qualitative risk analysis matrix – level of risk (AS/NZS 1999)

Likelihood	Consequences Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
A (almost certain)	H	H	E	E	E
B (likely)	M	H	H	E	E
C (moderate)	L	M	H	E	E
D (unlikely)	L	L	M	H	E
E (rare)	L	L	M	H	H

Note: The number of categories should reflect the need of the study.
E – Extreme risk, immediate action required; H – High risk, management attention needed;
M – Moderate risk, management responsibility must be specifies; L – Low risk, manage by routine procedures.

5.4 MELBOURNE WATER CASE STUDY – HAZARD ANALYSIS

The hazard analysis step is illustrated using the Melbourne Water consequence/probability matrix for the Silvan system primary disinfection plants and also reservoir management. Tables 5.3 and 5.4 show the consequence/probability matrix and significance scale respectively.

Table 5.3: Melbourne Water consequence/probability matrix

Ranking	Description, probability/frequency
Severity	
1	Insignificant
2	Minor impact for a small population
3	Minor impact for a big population
4	Major impact for a small population
5	Major impact for a big population
Likelihood	
1	0.001 or 1 in 1000 years
2	0.01 or 1 in 100 years
3	0.1 or 1 in 10 years
4	0.5 or 1 in 2 years
5	Almost certain

Physical, chemical and biological hazards were considered. Risks identified as high or very high (Table 5.4) were classified as significant, although control measures were identified for all risks.

Table 5.4: Melbourne Water significance scale

Significance	Likelihood				
	1	2	3	4	5
Severity					
1	negligible	negligible	negligible	negligible	low
2	negligible	negligible	low	medium	medium
3	low	low	medium	high	high
4	medium	high	high	very high	very high
5	high	very high	very high	very high	very high

Tables 5.5 and 5.6 show the application of the previous two Tables to chlorination of raw water and catchment collection and reservoir storage.

Table 5.5: Selected data from the Melbourne Water hazard analysis for chlorination of raw water at Silvan System primary disinfection plants

Hazard	Hazardous event, source/cause	Likelihood	Severity	Risk rating
Microbial	Inadequate disinfection method	4	4	very high*
Chemical	Formation of disinfection by-products at levels that exceed drinking water guideline levels	3	3	medium*
Microbial	Less effective disinfection due to elevated turbidity	4	4	very high*
Microbial	Major malfunction/failure of disinfection plant (i.e. no dosing)	2	5	high*
Microbial	Reliability of disinfection plant less than target level of 99.5%	3	4	high*
Microbial	Failure of UV disinfection plants	3	4	high*
Microbial	Low chlorine residual in distribution and reticulation systems	4	4	very high*
Microbial	Power failure to disinfection plant	4	5	very high*
Physical, Chemical Microbial	Contamination of dosing chemicals or wrong chemical supplied and dosed	4	5	very high*
Chemical	Over or under dosing from fluoridation plants	4	3	high*
Chemical Physical	Over or under dosing of lime for pH correction	4	3	high*

* Risks rated at high or very high are considered to be significant

Table 5.6: Selected data from Melbourne Water hazard analysis for protected water harvesting catchments and large storage reservoirs (Silvan Reservoir and catchment only)

Hazard	Hazardous event, source/cause	Likelihood	Severity	Risk rating
Microbial Turbidity Colour	Animals in catchment (native and feral animals)	5	2	medium
Microbial Physical Turbidity Colour	Storms in catchments	5	3	high*
Turbidity Colour Taste and Odour	Bushfire in catchment	2	5	very high*
Microbial Chemical (toxins) Taste and Odour	Algal bloom	2	4	high*
Microbial Turbidity Colour Chemical	Human access	5	2	medium
Microbial Turbidity Colour	Reservoir short circuiting	4	4	very high*

* Risks rated at high or very high are considered to be significant

5.5 KAMPALA CASE STUDY – HAZARD ANALYSIS

The hazard analysis step is illustrated using the Kampala consequence/probability matrix for the distribution systems. It should be noted that the time periods for likelihood are relatively short. This approach was used because both operational difficulties and the importance of other routes of exposure to most microbial pathogens and the low priority for chemical hazards meant longer-term risks were not considered to be priorities at this stage of water supply development.

When applying the hazard analysis within the distribution system, in a number of cases the severity varied depending on where the hazardous point was identified. For instance, different major valves control the flow to different numbers of people depending on where they are located within the system. Equally, the vulnerability of consumers also varied depending on socio-economic status and levels of coverage. Therefore, the hazard analysis also used data from a vulnerability map of the supply system to determine severity.

Table 5.7 illustrates the Kampala consequence/probability matrix. The significance scale is the same as that used by Melbourne Water (shown in Table 5.4).

Table 5.7: Kampala consequence/probability matrix (adapted from Deere *et al*. 2001)

Ranking	Description, probability/frequency
Severity	
Insignificant	Negligible impact in terms of severity of disease or numbers of people affected
Minor	Potentially harmful to a small population, morbidity but no mortality)
Moderate	Potentially harmful to a large population, morbidity but no mortality
Major	Potentially lethal to a small population, likely to be also significant morbidity
Catastrophic	Potentially lethal to a large population, likely to be also very significant morbidity
Likelihood	
Rare	Once every five years
Unlikely	Once per years
Moderate	Once per month
Likely	Once per week
Almost certain	Once per day

The principal hazards considered were microbial given the importance of infectious disease in Uganda. Chemical hazard consideration was primarily related to massive over-dosing of chlorine (for instance it had been noted in the late 1990s that toxic levels of free chlorine >5.0mg/l were detected in the Kampala at consumers taps). Risks identified as high or very high were classified as significant, although control measures were identified for all risks. The application of the consequence/probability matrix and significance scale is shown for water treatment works and the distribution system in Tables 5.8 and 5.9.

Table 5.8: Selected data from Kampala hazard analysis for water treatment works

Hazard	Hazardous event, source/cause	Likelihood	Severity	Risk rating
Quantity	Shallow intake resulting in close contact with algae, plastic bottles, polythene bags and blockage of raw water screen	Likely	Cat	Very high
Quantity	Tripping of raw water pumps and insufficient production due to clogging of screens	Likely	Cat	Very high
Microbial	Poor performance of Mannesman filters as air scourers are not all operational causing uneven filter bed formation and breakthrough of protozoa	Moderate	Major	high
Chemical	Excessive algal formations in Patterson filters due to irregular back washing of filters <18 hour intervals	Likely	Major	Very high
Microbial	No chlorine dosing on high level water due to lack of booster pumps	Likely	Cat	Very high
Microbial	Ineffective chlorination due to leaks in buried chlorine feeder line	Likely	Cat	Very high

Cat - Catastrophic

Table 5.9: Selected data from Kampala hazard analysis for distribution system

Hazard	Hazardous event, source/cause	Likelihood	Severity	Risk rating
Microbial	Birds faeces enter through vents because covers dislodged	Likely	Major	Very high
Microbial	Birds faeces enter through open inspection hatches	Likely	Major	Very high
Microbial	Ingress of contamination at inlet valve of service reservoir due to inundation of valve box and deteriorating valve packing	Moderate	Major	High
Microbial	Microbial contamination at valve V 391/V796/V-390, Block Map 2023	Likely	Moderate	High
Microbial	Microbial contamination at valve -1766/V1765 Block Map 2713	Likely	Moderate	High
Microbial	Area surrounding tap and sanitary condition of tap allow entry of contaminated water	Likely	Moderate	High
Microbial	Contaminated water enters through damaged pipes at road crossings	Moderate	Impact determined using risk maps (likely to be major)	High
Microbial	Contamination enters through exposed pipes in tertiary mains	Likely (NB: on-selling and public taps serve many people)	Moderate	High
Microbial	Poor hygiene in repair work allows microbial contamination to enter into the system	Unlikely	Cat	Very high
Microbial	Contamination of poorly maintained community tanks	Moderate	Moderate	Med

Cat – Catastrophic; Med - Medium

6

Control measures and priorities

The chapter outlines control measures for catchment protection, water treatment and piped distribution systems. All significant hazards in the water supply process, identified during the hazard analysis (Chapter 5) need to be identified as being controlled, or potentially controlled, by some mitigating process.

6.1 DETERMINE CONTROL MEASURES

In many instances control measures (often referred to as 'barriers') will already be in place, where this is the case they should be assessed to determine if they meet current (i.e. health-based target) requirements.

Control measures are identified by considering the hazardous events that can cause contamination of water, both directly and indirectly, and the activities that can mitigate the risks from those events. Control measures need to be identified at the point of contamination (where the hazardous event occurs) as well as downstream so that the effect of multiple barriers can be assessed together.

> Control Measures are those steps in supply that directly affect water quality and which, collectively, ensure that water consistently meets health-based targets. They are actions, activities and processes applied to prevent or minimise hazards occurring

Flow diagrams are particularly valuable to support the identification of control measures. This is because it simplifies the task conceptually. There are likely to be hundreds of control measures for a large system, or for a water safety plan covering many small systems. For example, control measures would include every point-of-use water treatment unit or each backflow prevention valve. To make the water safety plan simpler to develop, control measures that are alike can be represented on a flow diagram as one process step. One result of rolling up groups of control measures into single process steps is that relatively few key process steps emerge. In some case studies of water safety planning these process steps on the flow diagram are given the name Critical Control Points.

Control measures can be effective in reducing the levels of hazards in a number of ways:

- reducing their entry into the water supply,
- reducing their concentration once in the supply; or
- reducing their proliferation.

As control measures should be applied to the whole water supply process control measures for pathogenic and chemical hazards include those that relate to source protection and those that relate to engineered assets, such as well-head protection, drinking-water treatment plants, disinfection plants, storage reservoirs and backflow protection. Most control measures are non-engineered and, for example, many standard operating procedures include water safety considerations. Adherence to the work practice described in such a standard operating procedure can be considered a barrier to contamination and, therefore, a control measure and form an integral part of a water safety plan.

Source protection programmes are likely to include the most diverse control measures and, in some systems, the greatest total number. In many cases, activities to ensure the barriers are established and maintained may not be the sole responsibility of the water supplier, but may require multi-agency action.

6.1.1 Resource and source protection

Effective catchment management has many benefits. By decreasing contamination of source water, the amount of treatment and quantity of chemicals needed is reduced. This may reduce the production of treatment by-products and minimise operational costs.

Effective resource and source protection include the following elements:

- developing and implementing a catchment management plan, which includes control measures to protect surface and groundwater sources;
- ensuring that planning regulations include protection of water resources (land use planning and water shed management) from potentially polluting activities and are enforced; and
- promoting awareness in the community of the impact of human activities on water quality.

Examples of specific control measures are shown in Box 6.1.

Box 6.1: Examples of source water, storage and extraction control measures

Source water and catchments

- Designated and limited uses
- Registration of chemicals used in catchments
- Specific protective requirements (e.g. containment) for chemical industry or refuelling stations
- Reservoir mixing/destratification to reduce growths of cyanobacteria, anoxic hypolimnion and solubilisation of sedimentary manganese and iron
- pH adjustment of reservoir water
- Control of human activities within catchment boundaries
- Control of wastewater effluents
- Land use planning procedures, use of planning and environmental regulations to regulate potential water polluting developments
- Regular inspections of catchment areas
- Diversion of local stormwater flows
- Protection of waterways
- Runoff interception
- Security to prevent sabotage and tampering

Water extraction and storage systems

- Use of available water storage during and after periods of heavy rainfall
- Appropriate location and protection of intake
- Appropriate choice of off-take depth from reservoirs
- Proper well construction including casing, sealing and wellhead security
- Proper location of wells
- Water storage systems to maximise retention times
- Roofed storages and reservoirs with appropriate stormwater collection and drainage
- Securing tanks from access by animals
- Security to prevent unauthorised access, sabotage and tapping and tampering

6.1.2 Water treatment

After source water protection, the next barriers to contamination of the drinking-water system use water treatment processes. Source waters of very high quality may only require watershed protection and disinfection.

Control measures may include pre-treatment, coagulation-flocculation-settling, filtration and disinfection, examples are given in Box 6.2.

Box 6.2: Examples of treatment control measures

Water treatment system

- Coagulation/flocculation and sedimentation
- Alternative treatment
- Use of approved water treatment chemicals and materials
- Control of water treatment chemicals
- Process controllability of equipment
- Availability of backup systems
- Water treatment process optimisation including:
  - chemical dosing
  - filter backwashing
  - flow rate
  - minor infrastructure modifications
- Use of tank storage in periods of poor quality raw water
- Maintaining security to prevent sabotage and illegal tampering

Pretreatment includes roughing filters, microstrainers, off-stream storage and bank-side filtration. Pretreatment options may be compatible with a variety of treatment processes ranging in complexity from simple disinfection to membrane processes. Pretreatment can have the advantage of reducing, or stabilizing the microbial load to the treatment processes.

Coagulation, flocculation, sedimentation (or flotation) and filtration remove particles, including microorganisms (bacteria, viruses and protozoa). It is important that processes are optimised and controlled to achieve consistent and reliable performance. Chemical coagulation is the most important step in determining the removal efficiency of coagulation/flocculation/clarification processes. It also directly affects the removal efficiency of granular media filtration units and has indirect impacts on the efficiency of the disinfection process. While it is unlikely that the coagulation process itself introduces any new microbial hazard to finished water, a failure or inefficiency in the coagulation process could result in an increased microbial load entering drinking-water distribution.

Various filtration processes are used in drinking-water treatment, including granular, slow sand, precoat and membrane (microfiltration, ultrafiltration, nanofiltration and reverse osmosis) filtration. With proper design and operation, filtration can act as a consistent and effective barrier for microbial pathogens and may in some cases be the only treatment barrier (for example for removing *Cryptosporidium* oocysts by direct filtration when chlorine is used as the sole disinfectant).

Application of an adequate level of disinfection is an essential element for most treatment systems to achieve the necessary level of microbial risk reduction. Estimation of the level of microbial inactivation through the application of the CT concept (product of disinfectant concentration and contact time) for a particular pH and temperature required for the more resistant microbial pathogens ensures that other more sensitive microbes are also effectively controlled.

The most commonly used disinfection process is chlorination. Ozone, ultraviolet irradiation, chloramination and chlorine dioxide are also used. These methods are very effective in killing bacteria and can be reasonably effective in inactivating viruses (depending on type) and many protozoa, including *Giardia*. *Cryptosporidium* is not inactivated by the concentrations of chlorine and chloramines that can be safely used in drinking-water, and the effectiveness of ozone and chlorine dioxide is limited. However, ultraviolet light is effective in inactivating *Cryptosporidium* and *Giardia* and combinations of disinfectants can enhance inactivation.

Storage of water after disinfection and before supply to consumers can improve disinfection by increasing contact times. This can be particularly important for more resistant microorganisms, such as *Giardia*.

6.1.3 Piped distribution systems

Water entering the distribution system must be microbially safe and, ideally, should also be biologically stable. The distribution system must provide a secure barrier to post-treatment contamination as the water is transported to the user. Residual disinfection will provide partial protection against microbial contamination, but may also mask the detection of contamination through conventional faecal indicator bacteria such as *E. coli*, particularly by resistant organisms. Thus, water distribution systems should be fully enclosed and storages should be securely roofed with external drainage to prevent contamination. Backflow prevention policies should be applied and monitored. There should be effective maintenance procedures to repair faults and burst mains in a manner that will prevent contamination. Positive pressure should be maintained as far as possible throughout the distribution system. Appropriate security needs to be put in place to prevent unauthorised access and/or interference. Example control measures are outlined in Box 6.3.

Box 6.3: Examples of distribution system control measures

Distribution systems

- Distribution system maintenance
- Availability of backup systems (power supply)
- Maintaining an adequate disinfectant residual
- Cross connection and backflow prevention devices implemented
- Fully enclosed distribution system and storages
- Maintenance of a disinfection residual
- Appropriate repair procedures including subsequent disinfection of water mains
- Maintaining adequate system pressure
- Maintaining security to prevent sabotage, illegal tapping and tampering

6.1.4 Non-piped, community and household systems

These are covered in Chapter 13 'Small systems'.

6.2 MELBOURNE WATER CASE STUDY – CONTROL MEASURES

Tables 6.1 and 6.2 detail the control measures identified for each of the hazards, and associated hazardous event, identified in Tables 5.5 and 5.6 respectively.

Table 6.1: Control measures relating to significant risks identified for chlorination of raw water at primary disinfection plants

Hazard	Hazardous event, source/cause	Control measures
Microbial	Inadequate disinfection method	Minimising ingress of contamination from humans and domestic animals to system (closed catchments) and long reservoir detention times. Source water specifications. Research programme underway to further quantify pathogen loads and disinfection method.
Chemical	Formation of disinfection by-products	Reducing water age through tanks downstream where possible in periods of low water demand. Upstream preventative measures and reservoir management to minimise disinfection by-product precursors (eg managing off takes to avoid higher coloured water) Levels of by-products researched and below guideline levels.
Microbial	Less effective disinfection due to elevated turbidity	None downstream of disinfection. Research programme underway to quantify effect of increased turbidity on disinfection effectiveness. Catchment research completed to show very low levels of bacterial pathogens in raw water.
Microbial*	Malfunction/failure of disinfection plant (i.e. no dosing)	Chlorination plants refitted for equipment and process reliability of 99.5%. On-line chlorine residual monitoring and alarms for low chlorine dosing. Procedures in place to invoke major incident response in any case where chlorination plant off-line. (Standard Operating Procedure Zero Disinfection Event). Contingency Plan (Emergency Disinfection; Disinfection Plant Prolonged Failure; Zero Disinfection Event). Water quality monitoring.
Microbial*	Reliability of disinfection plant less than target level	Defined band widths for chlorine dosing. Plants have stand-by equipment and power.

Hazard	Hazardous event, source/cause	Control measures
	of 99.5%	
Microbial*	Failure of UV disinfection plants	Alarms on power and globe outages. Plant shut down if globes not functioning. Globes replaced annually.
Microbial*	Low chlorine residual in distribution and reticulation systems	Set point designed to achieve microbial standards at consumer taps. Dose rate at plant set to maintain residual.
Microbial*	Power failure to disinfection plant	Dual power source Diesel generator Telemetry
Physical, Chemical, Microbial	Contamination of dosing chemicals or wrong chemical supplied and dosed	Fluorosilic acid has lab certificate from the supplier. On-line monitoring controls. Raw material specification contracts.
Chemical	Over or under dosing from fluoridation plants	Plants have alarms on high and low levels with dosing cut-offs on high levels.
Chemical, Physical	Over or under dosing of lime for pH correction	Plants have alarms on high and low pH with dosing cut-offs on high pH.

* Hazards followed up in Chapter 7

Table 6.2: Control measures relating to significant risks identified for protected water harvesting catchments and large storage reservoirs

Hazard	Hazardous event, source/cause	Control measures
Microbial	Animals in catchment (wild cattle, deer, wallabies, wombats, feral animals)	Long detention times in large reservoirs. Feral animal control programme – shooting, baiting patrol. Downstream detention, disinfection control. Research programme to determine types of pathogens present in native and feral animals.
Microbial Physical	Storms in catchments	Some creeks can be turned out during storm events (Procedure for Operation of Harvesting Sources During Catchment Rainfall Event). Downstream long storage detention.
Turbidity Colour	Bushfire in catchments	Fire management and protection procedures. Bushfire management policy. Fire towers in catchment and patrols. Fire Management Plan. Fire Impacts and Preparedness Plan. Fire Protection Plan. Fuel Reduction Burning Guidelines.
Microbial Chemical	Algal Bloom	Routine plankton monitoring for all reservoirs. Targeted programme for at-risk reservoirs.

Hazard	Hazardous event, source/cause	Control measures
		Emergency Response Plan for Blue/Green Algal blooms.
Microbial	Human access	Closed catchment status (Melbourne Water By-Law 1 prohibits human entry into water supply catchments). Signage. Regular catchment patrols (Catchment Security Manual) and patrols logged in database. Long detention times in reservoirs. Perimeter catch drains around catchment security fence.
Microbial	Reservoir short circuiting	Long detention times. Risk to be quantified through reservoir hydrodynamic modelling research programme.

6.3 KAMPALA WATER CASE STUDY – CONTROL MEASURES

Tables 6.3 and 6.4 detail the control measures identified for each of the hazards, and associated hazardous event, identified in Tables 5.9 and 5.10 respectively.

Table 6.3: Control measures relating to selected significant risks identified at treatment works in Kampala

Hazard	Hazardous event, source/cause	Control measures
Quantity (Gaba 1)	Shallow intake resulting in close contact with algae, plastic bottles, polythene bags and blockage of raw water screen	Ensure intake is set at an appropriate depth by changing depth setting (‘floating intake’). Regular cleaning of area close to intake.
Quantity (Gaba 2)	Tripping of raw water pumps and insufficient production due to clogging of screens	Regular cleaning of screens to reduce clogging and maintain pumping rate
Microbial	Poor performance of Mannesman filters as air scourers are not all operational causing uneven filter bed formation and breakthrough of protozoa	Maintain adequate air scouring rates and ensure all scourers function to maintain even bed formation
Chemical	Excessive algal formations in Patterson filters due to irregular back washing of filters <18 hour intervals	Ensure backwashing occurs based on head loss and flow rate and minimum of every 18 hours
Microbial	No chlorine dosing on high level water due to lack of booster pumps	Dosing rates at 3kg/hr in low water level and then mixed with incoming water
Microbial	Ineffective chlorination due to leaks in buried chlorine feeder line	Maintain minimum of 1 mg/l free chlorine residual at all times

Table 6.4: Control measures relating to selected significant risks identified in the distribution system in Kampala

Hazard	Hazardous event, source/cause	Control measures
Microbial	Birds faeces enter through vents because covers dislodged	Vent covers remain in place and regularly maintained
Microbial	Birds faeces enter through open inspection hatches	Inspection covers are maintained in place and locked to prevent unauthorised entry
Microbial	Ingress of contamination at inlet valve of service reservoir due to inundation of valve box and deteriorating valve packing	Valve box is kept in good condition with adequate external and internal drainage; the structural integrity of box remains effective and the valve packing is in good condition
Microbial	Microbial contamination at valve V 391/V796/V-390, Block Map 2023	Good external and internal drainage; structural integrity of box; valve packing in good condition
Microbial	Microbial contamination at valve -1766/V1765 Block Map 2713	Good external and internal drainage; structural integrity of box; valve packing in good condition
Microbial	Area surrounding tap and sanitary condition of tap allow entry of contaminated water	Community operators and owners trained to keep area close to tap clean and maintain integrity of tap and riser
Microbial	Contaminated water enters through damaged pipes at road crossings	Pipes buried at depth on roadside, collars reinforce joints; regular maintenance
Microbial	Contamination enters through exposed pipes in tertiary mains	Keep all mains buried to design depths; provide secure designs for over-ground pipes; recovering of pipes exposed due to erosion
Microbial	Poor hygiene in repair work allows microbial contamination to enter into the system	Hygiene code for work on distribution mains is distributed and followed by all maintenance staff
Microbial	Contamination of poorly maintained community tanks	Cleaning regime for tanks established for community operators

7

Limits and monitoring

An operational limit (often defined as alert limit or action limit) is a criterion that indicates whether the control measure is functioning as designed. Exceeding the operational limit implies that action is required to prevent the control measure moving out of compliance. The term critical limit is often in some water safety plans to single out operational limits linked directly to absolute acceptability in terms of water safety.

Monitoring is the act of conducting a planned series of observations or measurements of operational and/or critical limits to assess whether the components of the water supply are operating properly.

For each control measure it is important to first define the operational limits (range) which, as part of the overall process train, leads to the supply of water that meets the intended use (including the health targets). However, because it is rarely practical to measure the concentration of hazards directly, some other means of control measure performance needs to be identified and becomes the target of monitoring. Therefore, a relationship between control measure performance, as determined by measurable parameters, and hazard control performance needs to be established. This relationship can be established using theoretical and/or empirical studies (see Validation in Chapter 11). In general long-term performance data, design specifications and objective scientific and empirical analysis are likely to be combined.

Not all measurable properties of control measures are suitable for this type of monitoring. Only where the following criteria are satisfied it is possible to define operational limits for control measures:

- limits for operational acceptability can be defined;
- these limits can be monitored, either directly or indirectly (e.g., through surrogates);
- a pre-determined corrective action (response) can be enacted when deviations are detected by monitoring (see Chapter 8);
- the corrective action will protect water safety by bringing the control measure back into specification, by enhancing the barrier or by implementing additional control measures; and
- the process of detection of the deviation and completion of the corrective action can be completed in a timeframe adequate to maintain water safety.

7.1 MONITORING PARAMETERS

The parameters selected for operational monitoring should reflect the effectiveness of each control measure, provide a timely indication of performance, be readily measured and provide opportunity for an appropriate response. Some water quality characteristics can serve as surrogates (or indicators) for characteristics for which testing is more difficult or expensive. Conductivity, for example, is a widely used surrogate for total dissolved solids. Examples of operational parameters during treatment processes and water distribution are outlined in Table 7.1.

Table 7.1: Examples of water treatment and distribution operational parameters

	Treatment step/process					
Operational parameter	Raw water	Coagulation	Sedimentation	Filtration	Disinfection	Distribution system
pH		✓	✓		✓	✓
Turbidity (or particle count)	✓	✓	✓	✓	✓	✓
Dissolved oxygen	✓					
Stream/river flow	✓					
Rainfall	✓					
Colour	✓					
Conductivity (total dissolved solids)	✓					
Organic carbon	✓		✓			
Algae, algal toxins and metabolites	✓					✓
Chemical dosage		✓			✓	
Flow rate		✓	✓	✓	✓	
Net charge		✓				
Streaming current value		✓				
Headloss				✓		
CT					✓	
Disinfectant residual					✓	✓
Disinfection by-products					✓	✓
Hydraulic pressure						✓

CT = Concentration x time

7.2 OPERATIONAL LIMITS

The water safety plan team should define the operational (or critical) limits for each control measure, based on operational parameters such as chlorine residuals, pH and turbidity, or observable factors, such as the integrity of vermin-proof screens and as shown in Table 7.1. The limits need to be directly or indirectly measurable. Current knowledge and expertise, including industry standards and technical data, as well as locally derived historical data, can be used as a guide when determining the limits. Target or operational limits might be set for the system to run at optimal performance while the term critical limits might be applied when corrective actions are required to prevent or limit the impact of potential hazards on the safety and quality of the water.

Limits can be upper limits, lower limits, a range or an envelope of performance measures. They are usually indicators for which results can be readily interpreted at the time of monitoring and where action can be taken in response to a deviation in time to prevent unsafe water being supplied.

7.3 MONITORING

Monitoring relies on establishing the 'what', 'how', 'when' and 'who' principles. In most cases, routine monitoring will be based on simple surrogate observations or tests, such as turbidity or structural integrity, rather than complex microbial or chemical tests. The complex tests are generally applied as part of validation and verification activities (see Chapter 11) rather than in monitoring operational or critical limits.

Table 7.2 shows what could be monitored if bacterial contamination of source water is identified as a potential hazard and feral or pest animal control and disinfection are identified as control measures. It can be seen from these examples that the frequency of monitoring will depend upon what is being monitored and the likely speed of change.

Table 7.2: Monitoring examples

	Animal control	Disinfection control
What?	Wild pig densities in catchment must be below 0.5 per km^2	Chlorine, pH, temperature and flow must provide for a CT of at least 15 with a turbidity of <5.0 NTU
How?	Scat (animal faeces) surveys in spatially stratified transects across the catchment	Measured via telemetry and on-line probes with alarms
When?	Annually	Telemetry is downloaded automatically and continuously monitored
Who?	Catchment officer	Telemetry engineer

If monitoring shows that an operational or critical limit has been exceeded, then there is the potential for water to be, or to become, unsafe. The objective is to monitor control measures in a timely manner to prevent the supply of any potentially unsafe water. A monitoring plan should be prepared and a record of all monitoring should to be maintained.

7.3.1 Monitoring plan

The strategies and procedures for monitoring the various aspects of the water supply system should be documented. Monitoring plans should include the following information:

- parameters to be monitored;
- sampling location and frequency;
- sampling needs and equipment;
- schedules for sampling;
- methods for quality assurance and validation of the sampling results;
- requirements for checking and interpreting the results;
- responsibilities and necessary qualifications of staff;
- requirements for documentation and management of records, including how monitoring results will be recorded and stored (see also chapter 10); and
- requirements for reporting and communication of results.

7.4 MELBOURNE WATER CASE STUDY – CRITICAL LIMITS AND MONITORING

A number of microbiological hazards were highlighted (by means of an asterisk) in Table 6.1, the control measures for these hazards are summarised in Table 7.3, along with critical limits and monitoring information.

Table 7.3: Critical limits and monitoring related to microbial hazards potentially affecting primary disinfection

Process step	Potential hazard	Control measures	Critical limits	Monitoring
Primary disinfection	Microbial	Operating Procedures for operation of treatment plants Chlorine residual must not be outside bandwidth for >45 min (for process correction – not product safety) Duplicate facilities (e.g. chlorinators, service water pumps, dosing lines, PLC) Backup power generation	No zero dosing*. Chlorine concentration is not to record zero for > 10 minutes. This allows for plant control loop time. Chlorine residual must not be outside bandwidth for > 24 hours. Refer to the Melbourne Water SCADA system for real time access to chlorine set points and low level chlorine alarms. Bands (digital alarm settings) are set at the plants. (* no power or intensity outages for UV plants)	On-line, continuous flow and chlorine residual at the plant controls dosing at a constant set-point. Responsibility: Operations – duty operator responds to alarms on residual. (Digital alarms at plants set on high and low bands. Low level alarms set for very low dosing).

7.5 KAMPALA CASE STUDY – CRITICAL LIMITS AND MONITORING

A number of microbial hazards were highlighted in Table 6.3 and 6.4, the control measures for these hazards are summarised in Table 7.4, along with critical limits and monitoring information.

Table 7.4: Critical limits and monitoring related to microbial hazards potentially affecting water production

Hazardous event	Potential hazard	Control measures	Critical limits	Monitoring
Blockage of shallow intake	Microbial	Set intake at appropriate depth and keep intake area clean		Pumping rates
Tripping of raw water pumps due to clogging of screens	Microbial	Regular cleaning of screens and maintain pumping rate	3,500m^3/hr at 2 pumps (1 in standby)	Pumping rates
Poor performance of Mannesman filters	Microbial	Maintain air scouring rate and ensure all scourers functional	38.7m^3/hr at 0.9bar	Scour rates
Excessive algal formations in Patterson filters	Chemical	Backwashing based on head loss and flow rate (minimum every 18 hours)	<7.7m/hour filtration rate	Filtration rates; inspection
No chlorine dosing on high level water	Microbial	Dosing rates at 3kg/hr in low water level and then mixed with incoming water	3kg/l chlorine dose per dosing pump	Chlorine dosing
Ineffective chlorination due to leaks in buried chlorine feeder line	Microbial	Maintain minimum of 1 mg/l free chlorine residual at all times	0.2-0.5mg/l residual chlorine <1NTU pH of 6.5-7	Free chlorine residual, turbidity, pH

Table 7.5: Critical limits and monitoring related to microbial hazards potentially affecting water distribution

Hazardous event	Potential hazard	Control measures	Critical limits	Monitoring
Birds faeces enter through vents because covers dislodged	Microbial	Vent covers remain in place and regularly maintained	All vents covered; action once 50% of vent support struts are damaged	Sanitary inspection by maintenance teams (daily); sanitary inspection water quality control staff monthly
Birds faeces enter through open inspection hatches	Microbial	Inspection covers are maintained in place and locked to prevent unauthorised entry	Inspection covers locked in place when not in use; Excess loss of chlorine residual	Sanitary inspection by maintenance teams (daily); sanitary inspection water quality control staff monthly; chlorine residual
Ingress of contamination at inlet valve of service reservoir	Microbial	Valve box is kept in good condition with adequate external and internal drainage; the structural integrity of box remains effective and the valve packing is in good condition	Tank structure sound with no cracks; drainage channels in good condition; action as soon as damaged noted	Sanitary inspection by maintenance teams (daily); sanitary inspection water quality control staff monthly; chlorine residual
Microbial contamination at valves	Microbial	Good external and internal drainage; structural integrity of box; valve packing in good condition	Valve boxes covered and do not have standing water or organic material in base; packing does not leak; no increase in turbidity; no loss of chlorine residual	Sanitary inspection (monthly) by operating staff; monthly to quarterly testing of turbidity and free chlorine by water quality control staff
Entry of contaminated water close to tap	Microbial	Community operators and owners trained to keep area close to tap clean and maintain integrity of tap and riser	No waste close to tap; tap and riser in good condition; no increase in turbidity, no loss of chlorine residual	Periodic sanitary inspection by community; periodic turbidity and free chlorine testing by water quality control staff

Hazardous event	Potential hazard	Control measures	Critical limits	Monitoring
Contaminated water enters at road crossings	Microbial	Pipes buried at depth on roadside, collars reinforce joints; regular maintenance	Pipes buried, no sign of leaks	Monthly to quarterly sanitary inspection by water quality control staff
Contamination enters through exposed pipes in tertiary mains	Microbial	Keep all mains buried to design depths; provide secure designs for over-ground pipes; recovering of pipes exposed due to erosion	All pipes buried or with secure protection; exposed pipes indicate action needed	Periodic sanitary inspection by water quality control staff; periodic inspection by community
Poor hygiene in repair work	Microbial	Hygiene code for work on distribution mains is distributed and followed by all maintenance staff	All workers have copy of hygiene code and follow requirements	Turbidity Chlorine residuals Site inspection
Contamination of poorly maintained community tanks	Microbial	Cleaning regime for tanks established for community operators	Tanks clean and in good condition; no increase in turbidity or change in appearance; no loss of chlorine residual; no community complaints	Periodic sanitary inspection by community and water quality control staff; turbidity and chlorine residual testing

8

Management procedures

If monitoring detects that a process is operating outside of the specifications of the critical or operational limits there is a need to act to restore the operation by correcting the deviation. An important component of a water safety is the development of corrective actions which identify the specific operational response required following specific devations from the set limits (operational and/or critical).

8.1 CORRECTIVE ACTIONS AND INCIDENT RESPONSE

The range of corrective actions can be diverse but, in an ideal system, the ability to change temporarily to alternative water sources is one of the most useful. More commonly, the use of backup disinfection plants or spot dosing may be used to correct disinfection system failure within the water supply. By ensuring that a contingency is available and promptly applied in the event of a deviation outside an operational or critical limit, safety and security of supply can be maintained.

> A Corrective Action is defined as the action to be taken when the results of monitoring indicate a deviation from an operational or critical limit.

It is necessary to detect a deviation through monitoring and respond through corrective action to prevent unsafe water being supplied, therefore, timing of response is an important consideration. For some control measures, such as chlorination, the monitoring may need to be on-line and may require instantaneous corrective action in response to a deviation. For others, such as control of animal densities in catchments, monitoring may only need to be annual and deviations may only require a corrective action to be applied over a period of months to years.

A corrective action might be initiated in response to deviations arising from events such as:

- non-compliance with operational monitoring criteria;
- inadequate performance of a sewage treatment plant discharging to source water;
- notification of chance events;
- spillage of a hazardous substance into source water;
- extreme rainfall in a catchment;
- unusual taste, odour or appearance of water.

Corrective actions typically comprise:

- accountabilities and contact details for key personnel;
- clear description of the actions required in the event of a deviation;
- location and identity of the standard operating procedures and required equipment;
- location of backup equipment;
- relevant logistical and technical information.

8.2 MELBOURNE WATER CASE STUDY – CORRECTIVE ACTIONS AND CONTINGENCY MEASURES

The corrective actions and contingency plan for microbial hazards potentially affecting primary disinfection are illustrated for selected control measures in Table 8.1.

Table 8.1: Corrective actions and contingency plan relating to microbial hazards potentially affecting primary distribution

Control measures	Critical limits	Monitoring	Corrective action	Contingency plan
Operating Procedures for operation of treatment plants Chlorine residual must not be outside bandwidth for >45 min (for process correction – not product safety) Duplicate	1) No zero dosing*. Chlorine concentration is not to record zero for > 10 minutes. This allows for plant control loop time. 2) Chlorine residual must not be outside bandwidth for > 24 hours.	On-line, continuous flow and chlorine residual at the plant controls dosing at a constant set-point.	Zero disinfection SOP. Process: Use duplicate facilities or consider plant shutdown Product: Manage flows SOP for spot dosing with chlorine,	*Zero disinfection event*

Control measures	Critical limits	Monitoring	Corrective action	Contingency plan
facilities (e.g. chlorinators, service water pumps, dosing lines, PLC) Backup power generation	(* no power or intensity outages for UV plants)		Notify retail companies (to flush zones, manage consumers)	

8.2 KAMPALA CASE STUDY – CORRECTIVE ACTIONS AND CONTINGENCY MEASURES

The corrective actions and contingency plan for hazards potentially affecting water production and distribution are illustrated for the control measure outlined in Table 8.2 and Table 8.3

Table 8.2: Corrective actions and contingency plan relating to microbial hazards potentially affecting water production

Control measures	Critical limits	Monitoring	Corrective action	Contingency plan
Flow through intake insufficient	3,745 m^3/hr; action when <3,000 m^3/hr (Gaba 1); 3,500 m^3/hr at 2 pumps (Gaba 2)	Pumping rates	Set intake at appropriate depth (Gaba 1), regular cleaning of screens (Gaba 2)	Ensure sufficient flow available during cleaning through on-site storage and timing of cleaning
Filter performance	38.7 m^3/hr at 0.9 bar (Mannesman); <7.7 m/hour filtration rate (Patterson)	Air scouring rates (Mannesman) filtration rate (Patterson)	Replace air scourers and automate filter operation (Mannesman); operational procedures for backwashing followed (Patterson)	Until air scourers replaced, inspected bed after scouring and manually relay bed if needed
Chlorination	Dosing rate 3 kg/hr low level and mix with high level; 0.2-0.5 mg/l residual chlorine <1 NTU pH of 6.5-7	Dosing rates and chlorine residual	Replace buried feeder pipe and install chlorinator on high level line	Back-up for shock chlorination must be place at all times

Table 8.3: Corrective actions and contingency plan relating to microbial hazards potentially affecting water distribution

Control measures	Critical limits	Monitoring	Corrective action	Contingency plan
Ensure sanitary integrity of service reservoirs	All vents and inspection covers maintained according to critical limits	Sanitary inspection, turbidity and chlorine residual testing by operators and water quality control staff	All vents immediately repaired on sign of damage. All operating staff trained to ensure inspection covers replaced	Facilities for shock chlorination at sites where contaminatio n suspected
All major valves are structurally secure and well drained	No signs of damage and adequate drainage, no debris in valve box	Sanitary inspection, turbidity and chlorine residual testing by operators and water quality control staff	Valve boxes are repaired as soon as damage or poor drainage noted, valve box cleaned	Community-utility communicati on network and rapid response team in place to respond to request
Tertiary mains buried and exposed pipes recovered	All pipes buried or with secure protection; exposed pipes indicate action needed	Periodic sanitary inspection by water quality control staff; periodic inspection by community	Pipes re-buried when exposed, community caretakers cover pipes when cover starts to become eroded	
Contaminated water enters at road crossings	Pipes buried, no sign of leaks	Monthly to quarterly sanitary inspection by water quality control staff	Repair leaks, bury pipes and reinforce joints	
Community tanks kept clean	Tanks clean and in good condition; no increase in turbidity or change in appearance; no loss of chlorine residual; no community complaints	Periodic sanitary inspection by community and water quality control staff; turbidity and chlorine residual testing	Community action to clean tanks; advice from NWSC staff on cleaning requirements	Where community tanks persistently insanitary, NWSC and environment al health staff can enforce cleaning by operators or remove licence from owners

NWSC – National Water and Sewerage Corporation

8.3 EMERGENCY MANAGEMENT PROCEDURES

No matter how thorough the water safety plan it is possible that unforeseen events or deviations may arise for which no corrective action is in place. Under such circumstances there is a need to develop corrective actions without warning. Although it is not possible to have specific and detailed corrective actions in place to respond to such scenarios, it is appropriate to have in place a generic emergency response plan for unpredictable events.

An emergency response plan would not have specific definitions of the operational and critical limits that, if deviated from, trigger a corrective action. Rather, the plan would include a protocol for situation assessment and the declaration of situations that require activation of the emergency response plan. This would include personal accountabilities and categorical selection criteria. The selection criteria may include:

- time to effect;
- population affected; and
- nature of the suspected hazard.

The success of emergency response depends on the experience, judgement and skill of the personnel operating and managing the drinking-water supply systems. However, generic activities that are common to many suspected contamination events can be incorporated within the emergency response plan. For example, for piped systems, emergency flushing standard operating procedures can be prepared, and tested, for use in the event that contaminated water needs to be flushed from a piped system. Similarly, standard operating procedures for rapidly changing or by-passing reservoirs can be prepared, tested and incorporated. The development of such a 'toolkit' of supporting material limits the likelihood of error and speeds up responses during emergency response situations.

The emergency response plans can be very broad and can include major regional disasters (such as earthquakes, floods, damage to electrical equipment by lightning strikes), accidents (spills in the watershed), damage to treatment plant and distribution system, and human actions (strikes, sabotage). Emergency response plans should clearly specify responsibilities for coordinating measures to be taken, a communication plan to alert and inform users of the supply, and plans for providing and distributing emergency supplies of water.

Emergency response plans should be developed in consultation with relevant regulatory authorities and other key agencies, and should be consistent with national and local emergency response arrangements. Key areas to be addressed in emergency response plans include:

- response actions, including increased monitoring;
- responsibilities and authorities internal and external to the organisation;
- plans for emergency water supplies;
- communication protocols and strategies, including notification procedures (internal, regulatory body, media and public); and
- mechanisms for increased public health surveillance.

During an emergency in which there is evidence of faecal contamination of the supply, it may be necessary either to modify the treatment of existing sources or temporarily to use alternative sources of water. It may be necessary to increase disinfection at source or to rechlorinate during distribution.

If possible, a piped distribution system should be kept under continuous pressure, as failure in this respect will considerably increase the risks of entry of contamination to the pipework and thus the possibility of waterborne disease. If the quality cannot be maintained, consumers should be advised to treat at the point of use (e.g. to boil the water during the emergency).

It is impossible to give general guidance concerning emergencies in which chemicals cause massive contamination of the supply, either caused by accident of deliberate action. The guideline values recommended in the *Guidelines for Drinking-water Quality* relate to a level of exposure that is regarded as tolerable throughout life; acute toxic effects are not normally considered. The length of time during which exposure to a chemical far in excess of the guideline value would be toxicologically detrimental will depend upon factors that vary from contaminant to contaminant. In an emergency situation the public health authorities should be consulted about appropriate action.

Following any emergency, an investigation should be undertaken and all involved staff should be debriefed to discuss performance and address any issues or concerns. The investigation should consider factors such as:

- What was the initiating cause of the problem?
- How was the problem first identified or recognised?
- What were the most essential actions required?
- What communication problems arose and how were they addressed?
- What were the immediate and longer-term consequences?
- How well did the emergency response plan function?

Appropriate documentation and reporting of the emergency should also be established. The organisation should learn as much as possible from the emergency to improve preparedness and planning for future emergencies. Review of the emergency response may indicate necessary amendments to existing protocols.

The preparation of clear procedures, accountabilities and equipment for the sampling and storing water in the event of an emergency can be valuable for follow up epidemiological or other investigations, and the sampling and storage of water from early on during a suspected emergency should be part of the response plan.

9

Supporting programmes

Many actions are important in ensuring water safety, but do not affect water quality directly, supporting programmes (Table 9.1) fall into this category.

> Supporting programmes are activities that ensure the operating environment, the equipment used and the people themselves do not become an additional source of potential hazards to the drinking-water supply.

They incorporate the principles of good process control that underpin the water safety plan. Codes of good operating, management and hygienic practices are essential elements of supporting programmes. These are often captured within standard operating procedures (SOPs) or system operating rules.

They can include, but are not limited to;

- hygienic working practices documented in maintenance SOPs;
- training and competence of personnel involved in water supply;
- tools for managing the action of staff, such as quality assurance systems;
- securing stakeholder commitment, at all levels, to the provision of safe water;
- education of communities whose activities may influence water quality;
- calibration of monitoring equipment; and
- record keeping.

Supporting programmes could specifically involve:

- Controlling access of people into treatment plants, catchments and reservoirs, and implementation of the appropriate security measures to prevent transfer of hazards from people when they do enter source water;

- Development of verification protocols for the use of chemicals and materials used in water supply, for instance to ensure use of suppliers that participate in international quality assurance programmes;
- Use of designated equipment for attending to incidents such as mains bursts. For example, equipment should be designated for potable water work only and not for sewage work; and
- Training and educational programmes for personnel involved in activities that could influence water safety. Training should be implemented as part of induction programmes and frequently updated.

Table 9.1: Examples of supporting programmes

Issue	Importance	Actions to be taken
Water supplier and/or resource protection agency have input into land-use and abstraction control in catchment	Source and resource protection are essential first steps in the delivery of safe water. Water suppliers and other key stakeholders should be able to influence land-use decisions to protect water sources	Development of water source protection plans. National groundwater and surface water management plans
Specifications for materials and chemicals used in water supplies	The control of chemical hazards derived from materials and chemicals used in water production is usually best achieved through product specification	Develop materials and chemicals specifications. Require certification of quality by a laboratory holding ISO/IEC17025 accreditation
Training of operation and maintenance staff	Poor operational practice may lead to large-scale contamination and increased public health risks	Training programmes and ongoing supervision systems in place
Hygiene code of practice for work on the system developed and made available to all staff	Staff unaware of, and do not follow, satisfactory hygiene practices	Ensure hygiene code is clear and easy to follow, and copies kept in every vehicle used by operational teams who should be trained in their use
Training and hygiene education in communities	Poor hygiene practices increase risks within the home and may also affect environmental hygiene and cause contamination of supplies	Develop participatory awareness-raising and education programmes
Groundwater mapping, assessment of vulnerability and definition of protection zones	Location and vulnerability of groundwater reserves not known	Develop hydrogeological maps and a national or regional groundwater management plan

Supporting programmes will consist almost entirely of items that water suppliers and handlers will ordinarily have in place as part of their normal operation. For most, the implementation of supporting programmes will involve:

- collation of existing operational and management practices;
- initial, and thereafter, periodic review and updating to continually improve practices;

- promotion of good practices to encourage their use; and
- audit of practices to check that they are being used, including taking corrective actions in case of non-conformance.

Comparison of one set of supporting programmes with those of others, through peer review, benchmarking and personnel or document exchange, can stimulate ideas for improved practice.

9.1 MELBOURNE WATER CASE STUDY – SUPPORTING PROGRAMMES

Supporting programmes make up a major part of Melbourne Water's water safety plan, as illustrated in Table 9.2.

Table 9.2: Melbourne Water supporting programmes

Supporting programme	Document reference	MW Contact
Melbourne Water Policies		
Risk Management Policy	MW Intranet – Policies	Corporate Secretary & Legal Counsel
Public Health Policy	MW Intranet – Policies	Group Manager Research & Technology
Water Supply Catchment Policy	MW Intranet – Policies	Catchments & Waterways
Contract Management		
Bulk Water Supply Agreements	MW Intranet – Operations	Operations
Capital delivery (design briefs, contract specs, commissioning, handover)	Registered files	Manager Treatment Capital Delivery
Chemical supply contracts (including security measures and quality compliance)	Registered files	Business Services and Operations
Operating and Maintenance Procedures		
Standard Operating Procedures (SOPs) for Water Treatment	MW Intranet – Operations – Standard Operating Procedures	Team Leader Water Supply Operations
Catchment management plans and procedures	Refer to the Source Water Specifications	Catchments & Waterways
Raw material control and vendor assurance program	MW Intranet and supply contract files	Section Leader North West Water Operations
Controls and Standard Operating Procedures for transfer/distribution	MW Intranet Water Transfer	Operations
	Bulk Water Entitlement Operating Rules	Operations
	Annual System Operating Plan	Team Leader Water Supply Operations
Reservoir inspection/security procedures	MW Intranet Operations - SOPs	Operations
	MW Intranet Water Operations - SOPs	Operations
	MW Intranet –Operations – SOPs – Water – Emergency Events	Operations Area Leaders

Supporting programme	Document reference	MW Contact
Incident Management		
PERFORM (Incident and Crisis Management Plan)	Melbourne Water Program and Management Document "Prompt Emergency Response for Melbourne" MW Intranet Management Systems – Incident Management	Risk and Compliance Manager, Corporate Secretariat
	Incident Records Operations and Asset Management and Capital Delivery	Operations & Infrastructure
Contingency Plans	MW Intranet – Management Systems - Incident Management – Contingency Plans	Operations
Emergency Event Standard Operating Procedures	MW Intranet –Operations – SOPs – Water – Emergency Events	Operations
Customer Feedback		
Defined in the Bulk Water Supply Agreement	MW Intranet – Operations - Customers	Team Leader Water Supply Operations
Monthly customer reports	Registered files	Operations
Quarterly and annual public health reports	Registered files	Research & Technology
Asset Management		
Asset Condition Assessment	State of the Assets Report	Infrastructure
Maintenance: Routine and Non-routine	Hansen database to access SMIs and work orders Mech/elec. And civil contracts Routine maintenance checklists O&M manuals	Infrastructure
Maintenance: Annual Outages Program		Team Leader Water Supply Operations
Improvement Strategies		
Drinking-water Quality Strategy	Registered files	Planning
Mornington Peninsula Strategy	Registered files	Planning
Environment and Public Health		
Environment and Public Health Management System Manual	MW Intranet – Management Systems	Research and Technology
Quality Management System for Drinking-water Quality QMS Manual	MW Intranet – Management Systems	QMS HACCP Coordinator
System Procedures: Non-conformance & Corrective and Preventative Action Procedure Management Review Procedure Internal Audit Procedure	MW Intranet – Management Systems	Research & Technology
Research &Development Program		
R&D Program	Registered files	Research & Technology
Water Quality Monitoring		

Supporting programme	Document reference	MW Contact
Water Quality Monitoring Program	Registered files	Water Supply Operations
Procedure for managing water quality monitoring	Registered files	Water Supply Operations
Compliance Reporting		
Customer report – monthly (compliance with BWSA, including exceedence reporting)	Registered file	Water Supply Operations
Internal operational reports (KPIs etc.)		
Quarterly and Annual Public Health Reports		Water Supply Operations
Fluoride reports to Department of Human Services		Water Supply Operations
Managing Directors Report		Commercial Services
Document and Records		
Document Management Procedure	MW Intranet – Policies	Commercial Services
Records Management Policy	MW Intranet – Policies	Commercial Services
Training		
Performance Improvement Policy and Procedure	MW Intranet – Policies	Human Resources
Performance Planning Policy	MW Intranet – Policies	Human Resources
Skill-based pay system for water supply operators	Personal files Operator Skills Matrices	Human Resources
HACCP Awareness Training	Registered file and computer file location	QMS HACCP Coordinator
Records	MW Training Database	Human Resources

MW – Melbourne Water; HACCP – Hazard Analysis Critical Control Point

9.2 KAMPALA CASE STUDY – SUPPORTING PROGRAMMES

NWSC have or participate in a number of supporting programmes that support the delivery of safe drinking-water. The establishment of ‘water quality control’ as a department is an important step in promoting improved water safety management. The establishment of the water safety taskforce and investment in improving monitoring points and mapping of the distribution system are essential supporting programmes for the successful implementation of the water safety plan.

Training of staff is a key supporting programme for NWSC and they continue to ensure that staff are appropriately trained and understand the importance of water safety. The distribution system in Kampala is managed by a private contractor and the water safety plan has been incorporated into arrangements with the contractor to ensure performance. More generally, NWSC are applying more generic management systems to all aspects of its work.

NWSC have also embarked on a number of activities to improve uptake of services among the population of Kampala, particularly within poor areas. This will enhance the overall reduction in water-related health risks and will provide further resources for water safety management. As part of this activity, pilot level activities are underway to provide training and tools for communities to better manage the tertiary infrastructure, where contamination within the distribution system most commonly occurs. This approach includes provision of training in sanitary inspection and local level action, as well as developing more effective communication channels between consumers and the utility.

NWSC remain a key player in developing appropriate drinking-water standards for Uganda, the use of the water safety plan and risk assessment data feeds into the broader sector dialogue regarding levels of water safety. Other supporting programmes include participation in the Lake Victoria Environmental Management Plan, which is a multi-country effort to improve the quality of the lake. As the major source of water for several NWSC supplies, this is critical and will become more so as services are rolled out. NWSC also control the sewerage system in Kampala and are therefore responsible for implementing discharge consents on industry. As the overall rate of connection to sewerage is limited in Kampala, NWSC are embarking on the development of a sanitation master plan for the city in collaboration with other key stakeholders.

10

Documentation and record keeping

This chapter summarises the content of a water safety plan document and also outlines the record keeping that will form part of its implementation. Documentation and records are essential for reviewing the adequacy of the water safety plan and the adherence of the water supply system to the plan.

10.1 DOCUMENTING THE WATER SAFETY PLAN

Table 10.1 details the proposed content of a water safety plan and, where appropriate, the relevant chapter within this document dealing with that area.

Table 10.1: Proposed content of a water safety plan

Component	Chapter	Must contain	Should contain	May contain
Water safety plan team chart	3	X		
Detailed description of the supply, intended use and vulnerability	3 and 4	X		
Process flow diagram including control measures	4 and 6	X		
Hazard identification	5	X		
Documented corrective actions	8	X		
Source water protection programme		X		
Documented incident procedure	8		X	
Supplier policy documents for supporting programmes	9		X	
Detailed specifications for chemicals and materials used in the water supply			X	
Job descriptions for those holding principal accountabilities for operating the water safety plan			X	
Record-keeping procedures	10		X	
Validation data	11		X	
Procedures for verification and revision	11		X	
Relevant Good Manufacturing Practice manuals (including line hygiene, preventative maintenance, and equipment calibration measurements)				X
Job descriptions and accountabilities for all staff				X
Training programme and records for all staff				X
Laboratory manuals (including calibration procedures)				X
Findings and corrective actions from previous audits (including verification procedures)				X
Customer complaint policy and procedure				X

10.2 RECORD KEEPING AND DOCUMENTATION

In addition to the actual water safety plan there will also be a range of records that will form part of the water safety plan setting up and implementation process as well as monitoring and any necessary corrective actions taken, incident response records, validation and verification. These can essentially be divided into four types of record:

- support documentation for developing the water safety plan;
- records generated by the water safety plan system;
- documentation of methods and procedures used; and
- records of employee training programmes.

Water safety plan system records are kept to demonstrate adherence of the system to the water safety plan. By tracking records generated by the water safety plan system, an operator or manager can become aware that a process is approaching its operational or critical limit (see Chapter 7). Review of records can be instrumental in identifying trends and in making operational adjustments. Periodical review of water safety plan records is recommended so trends can be noted and appropriate actions decided upon and implemented.

Documentation and records systems should be kept as simple and focused as possible. The level of detail in the documentation of procedures should be sufficient to provide assurance of operational control when coupled with a suitably qualified and competent operator.

Mechanisms should be established to periodically review and, where necessary, revise documents to reflect changing circumstances. Documents should be assembled in a manner that will enable any necessary modifications to be made easily. A document control system should be developed to ensure that current versions are in use and obsolete documents are discarded.

Appropriate documentation and reporting of incidents/emergencies should also be established. The organisation should learn as much as possible from an incident to improve preparedness and planning for future events. Review of an incident may indicate necessary amendments to existing protocols, and may suggest that upgrading of the water system is required (see Chapter 11).

10.3 MELBOURNE WATER CASE STUDY -DOCUMENTATION

For online controls of chlorine dosing and plant operation, real time information is collected on a SCADA (Supervisory Control and Data Acquisition) telemetry system. Plant log records are kept by water supply operators and include documentations such as:

- calibration records;
- plant maintenance reports; and
- manual verification of plant performance.

Other documentation that arises from disinfection for Melbourne Water includes:

- reporting of deviation of critical limits to the Department of Human Services and the retail water companies;
- reporting of annual performance in the Melbourne Water annual report;
- on-going reporting to executive and Board members of disinfection performance; and
- internal and external auditing for the Melbourne Water Quality Management System which includes Hazard Analysis and Critical Control Point (HACCP) and ISO 9001:2000. This involves the generation of audit reports, improvement notices and actions.

10.4 KAMPALA CASE STUDY - DOCUMENTATION

The principal document to support the water safety plan is a water safety plan operational guide for the water quality control department and a range of tools for use by water quality, water production and operational staff. This also includes documentation of the risk assessment and documents and tools for engaging with communities regarding community-based actions to improve water quality. A code of hygienic working is also available. In addition, all treatment works have appropriate operational manuals.

Internal auditing of water safety through regular monitoring and verification is also practiced. A regular dialogue is maintained with the Ministry of Health and Directorate of Water Development to ensure transparency in the water safety management plan.

11

Validation and verification

Validation and verification are important to establish that components within the water safety plan are working as expected and that the water safety plan as a whole is delivering the required results.

11.1 VALIDATION

Validation should be targeted at the assessment of the scientific and technical inputs into the water safety plan. Validation should ensure that the information supporting the plan is correct and that the elements of the water safety plan will be effective, thus enabling conformity with health-based targets (see Chapter 12) and public health policy.

> Validation involves obtaining evidence that the elements of the water safety plan are effective.

Process validation is required to show that treatment processes can operate as required. It can be undertaken during pilot stage studies, during initial implementation of a new or alternative water treatment system and is a useful tool in the optimisation of existing treatment processes. Table 11.1 details the validation of the critical limits, relating to coagulation and flocculation, for the Molendinar water purification plant, operated by Gold Coast Water (Australia), which was outlined in Figure 4.3.

Table 11.1: Validation schedule for critical limits, relating to coagulation and flocculation, at the Molendinar water purification plant

Control measure	Critical or operational limit	Validation	Comments
Coagulation, flocculation & settling – raw water inlet flow			
	Inspect daily / calibrate monthly	Refer comments	The inlet flow measuring device is important because the output from several dosing pumps is dependent upon its accuracy. Experience has shown that the instrument drifts only minimally over a one month period. However, it is easy for operators to do a visual check of the unit daily for mechanical failure and therefore, because of criticality, it is included in the daily plant check (proc. TS-01-210)
Coagulation, flocculation & settling – alum dosing			
	Treated water true colour of < 5 cpu	ADWG (1996) for True Colour	ADWG specify <15 c.p.u. however, 5 C.P.U. has been selected as a Critical limit for corrective action because colour above 5 is noticeable in larger volumes and colour above this value would be indicative of non optimal dosing that would affect other water quality parameters
Coagulation, flocculation & settling – pH control of dosed water			
	6.5 to 7.0 (low manganese conditions). 7.0 to 7.3 (permanganate dosing conditions)	AWWA "Water Quality and Treatment" 4th Edition (chapter 6) See also 'Manganese & Iron Related Problems in Aust Drinking-water Supplies" at (www.clo2.com/reading/ drinking/iron.html)	Although a range of values is shown, set points will be in force at any given time and procedures dictate that significant deviations will be investigated. The range 6.5-7.0 is close to the solubility minimum for Alum. Set points in the range 6.7 or 6.8 are common to minimise the amount of pH correction in disinfection and this is arbitrary. The reaction of permanganate with manganese will yield increased Mn^{2+} if an acid environment persists. This is undesirable. Refer also procedure TS-01-209 'Molendinar dosed water pH'
Coagulation, flocculation & settling – carbon dioxide dosing			

Control measure	Critical or operational limit	Validation	Comments
	Treated water alkalinity of 35 to 50 mg/l as $CaCO_3$	Experimental value	GCW is attempting to overcome the phenomenon of "pH bounce" in concrete lined pipes. This occurrence results in some consumers receiving high pH water. The higher the alkalinity the greater the resistance to pH bounce. The figure of 35 to 50 (suggested by Hunter Water) is a considerable increase over the current figure of about 20. Distribution system pH monitoring of trouble spots indicates this level of alkalinity is probably adequate. Further data is required to optimise dosing.
Coagulation, flocculation & settling – pre-filter chlorination			
	Treated Water soluble Mn levels of < 0.02 mg/l	Experimental work carried out for GCW by University of Qld. In 1986 Report entitled "Investigation into Biological Manganese Oxidation and Deposition in the Gold Coast Water Distribution System" by Dr. L. Sly	Report recommended that treated water should have less than 0.01 mg/l soluble Mn . Under normal operating conditions this is achieved. A figure of 0.02mg/L can be tolerated for short periods of time and this figure is chosen for corrective action instigation. Refer procedures TS-01-207 and 211 regarding manganese removal.

ADWG – Australian Drinking Water Guidelines
AWWA – American Water Works Association

Evidence for validation of the water safety plans can come from a variety of sources, including the scientific literature, trade associations, regulation and legislation departments, historical data, professional bodies or supplier knowledge. This can inform subsequent testing requirements, including the use of specific pathogens or indicator microorganisms. Microbial parameters, such as heterotrophic plate counts and coliform enumeration, which may be inappropriate for operational monitoring, can be used for validation purposes and the design of treatment systems as this does not form part of the routine day-to-day monitoring and management and thus the lag time in receiving the results is not a problem.

11.2 VERIFICATION

Verification may include review of monitoring control measures, microbiological and chemical testing, or review of the water safety plan overall to ensure that it is still accurate. This may be necessary, for instance, if there have been changes to processes or equipment.

> Verification is the use of methods, procedures or tests in addition to those used in monitoring to determine if the water safety plan is in compliance with the stated objectives outlined in the water quality targets and/or whether the water safety plan needs modification and revalidation.

To verify system performance, periodic checks are necessary.

11.2.1 Microbial water quality

For microbial quality, verification is likely to include some microbiological testing. In most cases it will involve the analysis of faecal indicator microorganisms (for further details see Dufour *et al*. 2003), but in some countries it may also include assessment of specific pathogen densities. Verification for microbial quality of drinking-water may be undertaken by the supplier, surveillance agencies or a combination of the two.

Approaches to verification include testing of source water, treatment end-point product and water in distribution systems or stored household water. Verification of microbial quality of drinking-water includes testing for *Escherichia coli* as an indicator of faecal pollution. *E. coli* provides conclusive evidence of recent faecal pollution and should not be detected. In practice, the detection of thermotolerant coliform bacteria can be an acceptable alternative in many circumstances. While *E. coli* is a useful indicator it has limitations. Enteric viruses and protozoa are more resistant to disinfection and consequently the absence of *E. coli* will not necessarily indicate freedom from these organisms. Under certain circumstances it may be desirable to include analysis for more resistant microorganisms such as bacteriophages and/or bacterial spores. Such circumstances could include the use of source water known to be contaminated with enteric viruses and parasites or high levels of viral and parasitic diseases in the community.

Water quality can vary rapidly and all systems are subject to occasional failure. For example, rainfall can greatly increase the levels of microbial contamination in source waters and waterborne outbreaks often occur during and shortly after storms. Results of analytical testing must be interpreted taking this into account.

11.2.2 Chemical water quality

Assessment of the adequacy of the chemical quality of drinking-water relies on comparison of the results of water quality analysis with guideline values. For additives, i.e., chemicals deriving primarily from materials and chemicals used in the production and distribution of drinking-water, emphasis is placed on the direct control of the quality of these products. In controlling drinking-water additives, testing procedures typically assess the contribution of the additive to drinking-water and take account of variations over time in deriving a value which can be compared with the guideline values.

Some hazardous chemicals that occur in drinking-water are of concern because of effects arising from single exposures or sequences of exposures over a short period. Where the concentration of the chemical of interest varies widely, even a series of analytical results may fail to fully identify and describe the public health risk. In controlling such hazards, attention must be given to both knowledge of causal factors and trends in detected concentrations, since these will indicate whether a significant problem may arise in the future. Other hazards may arise intermittently, often associated with seasonal activity or seasonal conditions. One example is the occurrence of blooms of toxic cyanobacteria in surface water.

11.3 MELBOURNE WATER CASE STUDY - VALIDATION

The validation for the primary disinfection control measure outlined in Table 7.3 is shown in Table 11.2.

Table 11.2: Validation of the primary disinfection control measure

Critical limits	Validation	Further investigation	Review schedule
No zero dosing*. Chlorine conc. is not to record zero for > 10 minutes. This allows for plant control loop time. (* no power/intensity outages for UV plants)	Upstream processes (initial kill): The set points have been calculated to achieve a minimum contact time of approximately 30 minutes with a residual >0.5 mg/l and CT≥ 15mg/l.min minimum. This will achieve at least 99% inactivation of viruses and bacteria (Ref: WHO Guidelines for Drinking-water Quality, Volume 2, 1994; Australian DrinkingWater Guidelines, National Health and Medical Research Council).	Knowledge on the significance of protozoa from protected sources and large detention times. Research programme underway. Completed research programme shows that protected catchments afford a three order magnitude reduction in parasitic protozoa and bacterial pathogens.	Annually
Chlorine residual must not be outside bandwidth for > 24 hours.	Bacterial regrowth downstream: Set points are based on achieving the retail company licence and National Health and Medical Research Council 1987. Guideline requirements for coliforms at taps and entry points, while maintaining chlorine concentrations below a level which will incur objectionable taste and odour.	Water Filter Study showed that there was no significant public health benefit measured from filtering the supply. Significance of chlorine residual to taps is being addressed by research in the water industry. Significance of total coliforms as health indicators has been assessed and has been removed as a health criteria in 2004 Australian Drinking Water Guidelines	

11.4 KAMPALA CASE STUDY – VALIDATION AND VERIFICATION

In Kampala, a risk assessment was performed on the system to assess current performance and as a means of validating whether the water safety plan would deliver water considered safe (Howard and Pedley 2003). The assessment took the form of assessment of removal of selected microbial indicators and index organisms through the treatment works (*E.coli*, *Clostridium* perfringens and coliphage) and analysis of indicator organisms (*E.coli* and faecal streptococci) in the distribution system. A quantitative risk assessment was performed, using a well-defined set of assumptions regarding the relationship between organisms analysed and pathogen groups. The process utilised the simplified methodology outlined in the WHO *Guidelines for Drinking-Water Quality, 3rd edition* (WHO 2004).

The assessment demonstrated that effective implementation of the water safety framework ensured adequate bacterial quality from the treatment works, although as the source water was of high quality this was expected. The assessment demonstrated that risks were much greater in the distribution system and therefore emphasised the need for improved safety management within the network following the water safety plan.

The assessment did indicate that the treatment works provided far less security regarding the risk from protozoan pathogens, a result again expected given that the plants were not designed with protozoa removal in mind. It was concluded that greater security could be obtained in one treatment works through better operation, but in the second investment would be required to upgrade the system. However, bearing in mind that overall rates of connection were low, alternative supplies were grossly contaminated and that poor hygiene and inadequate sanitation were likely to account for a greater proportion of pathogen transmission, it was recommended that such investment was a relatively low priority.

Verification is achieved through a number of mechanisms. At the treatment works, a regular programme of testing for *E.coli* was established (following previous practice, but with reduced frequency) and the laboratory was equipped to perform analysis of *Clostridium perfringens* as a means of testing treatment efficiency. Treatment plant audits are also undertaken on a regular basis to review operational records.

A rolling programme of testing for *E.coli* and sanitary inspection is also implemented for the distribution system. Periodic testing of faecal streptococci is also performed. These processes provide the water quality control department with data on which to ensure that the water safety plan is delivering safe drinking-water and can be incorporated into periodic risk assessments using available data.

Table 11.3 summarises the verification procedures.

Table 11.3: Validation of the primary disinfection control measure

Unit Process	Verification		
	What	When	Who
Source Water	Operational reports and audit	Monthly	WQCD
Coagulation/Flocculation	*E. Coli*	Weekly	WQCD
	Faecal streptococci	Weekly	
	Clostridium perfringens	Weekly	
	Record audit	Monthly	
Filtration	*E. Coli*	Weekly	WQCD
	Faecal streptococci	Weekly	
	Clostridium perfringens	Weekly	
Disinfection	*E. Coli*	Weekly	WQCD
	Faecal streptococci	Weekly	
	Clostridium perfringens	Weekly	
	CT values	Weekly	
Distribution System	*E. Coli*	Monthly	WQCD
	Faecal streptococci	Monthly	

WQCD – Water Quality Control Department

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:	$C_D = C_R \times (1 - PT)$ $E = C_D \times V$ $P_{inf,d} = E \times r$			

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

13

Water safety plans for small systems

Small, community-managed water supplies are found in both developed and developing countries worldwide. A wide range of technologies may be employed in such supplies, from relatively sophisticated treatment plants (sometimes of a 'package' nature) serving customers with in-house connections, to single point sources such as a tubewell or borehole fitted with a handpump. The common feature, however, of all such small water supplies is that operation and maintenance is performed by members of the community with limited specialist skills, who can commit only limited amounts of time and who frequently receive little or no financial remuneration or formal training. Furthermore, the range of available equipment to identify and rectify faults may be limited as is access to water quality testing equipment. There is often a significant degree of reliance on external bodies (usually an arm of local or national Government) to provide support for problems beyond the capacity of the community operator to resolve (for instance rehabilitation) and in providing general guidance.

13.1 PRIORITISING HAZARDS

The development of water safety plans for small systems should focus on the control of microbial quality and in particular pathogens derived from faecal contamination. Studies from both developed and developing countries highlight the vulnerability of small systems to microbial contamination (Gelinas 1997; Howard *et al*. 2003; Fewtrell *et al*. 1998). The risks of microbial contamination are more significant in shallow aquifers, which may show significant changes in quality in response to rainfall (Wright 1985; Barrett *et al*. 2000). Deeper aquifers tend to have better and more stable microbial quality. Where small systems include piped distribution with connections at a 'within-house level of service' feeding showers there is a risk from *Legionella*, although control strategies may require greater involvement by external bodies as this may be beyond the capacity of community operators to control.

Chemical hazards are most likely to result from either natural sources or agricultural pollution. Of the natural chemicals, arsenic and fluoride are likely to be the most significant problems facing small systems. Nitrate and pesticides may be found in areas of agriculture (and on-site sanitation in the case of nitrate) and lead may be problem in older distribution systems. Problems of chemical contamination may also be found with rainwater collection in areas with high air pollution or where chemicals leach from roofing material.

By preference, the assessment of risks posed by chemicals in water should be based on data derived from water quality tests performed on samples of water taken from water supplies before commissioning. However, it is unlikely that such data exist for all supplies and therefore risk assessment may be based on an incomplete set of data. The WHO document 'Chemical Safety of Drinking-water: assessing priorities for risk management' (Thompson *et al*. 2004) provides further guidance in how to identify chemicals likely to pose the greatest risk to health in a country or region or water supply employing a particular technology type. Although chemical quality in deeper groundwater is often stable, in shallow groundwater chemical quality may vary significantly with rainfall and seasonal fluctuations have been noted for arsenic and nitrate (Barrett *et al*. 2000).

The water safety plan should propose control measures for chemical hazards where possible. However, in most cases, the control of these hazards must be addressed at the design stage (for instance by setting appropriate intake depths) rather than operational controls. Monitoring is unlikely to be feasible by the operators of small systems and therefore any water quality testing will necessarily devolve to the surveillance agency. This further supports the need for the water safety plan to focus on microbial quality in smaller systems.

13.2 SMALL SYSTEM APPROACHES

The nature of small, community-managed water supplies means that the operators of the water supply are unlikely to have the necessary skills to develop system-specific water safety plans without outside assistance. Therefore, water safety plans must either be developed for the supply, or detailed guidance must be provided to ensure that local water safety plans can be developed. Two approaches are therefore envisaged to support small systems:

- development of *generic water safety plans* for particular technologies to be applied across a region or country; or,
- development of *guides* that support the local development of a water safety plan, with examples (model water safety plans) provided that may be modified according to local conditions.

Either approach may be applied in different situations depending on the resources available within communities. Both approaches may be used in a single country. In both developed and developing countries, very small water supplies serving relatively few households would be most likely to require the development of a generic water safety plan for the technology used. Appendix B provides examples of generic water safety plans that can be adapted to circumstances in different countries and/or regions. These could also function as model water safety plans.

In larger communities, including small towns, the capacity of communities to use guidance material to develop water safety plans may be much greater. The greater complexity of the supplies and wider range of hazardous environments that could occur will also make it desirable that water safety plans be tailored to the conditions in individual supplies.

In developing water safety plans for small systems, the implementation of the plans will be highly dependent on the training and resource material made available to operators. This is also likely to require ongoing support in maintaining the water safety plan and providing periodic updating. This is often a role that the surveillance agency will play, in addition to their role in independent assessment of water safety.

13.3 DEVELOPING GENERIC TECHNOLOGY WATER SAFETY PLANS

Generic technology water safety plans should be based on a thorough understanding of the hazards and risks that may threaten each type of technology. These may include, for example, lack of covers on wells allowing direct ingress of contaminated surface water, lack of drains that allow inundation of the wellhead, animal access close to the wellhead leading to the development of pathways into the source and faecal material close the source. For situations where there are many small supplies these cannot be tailored to each individual water supply, although it is possible to define a generalised list of hazardous events and associated risks for the settings in which such systems will be found.

The first stage in this process is to identify the range of technologies that exist within the country/region for which generic water safety plans will be developed. This may involve consideration of technologies installed by organisations other than a Government water supply agency (for instance by non governmental organizations). Variations in construction and design of the small systems should also be considered, as these may influence both the types of hazardous event that may occur and the risk (in particular the likelihood) associated with a hazardous event. For instance, contamination introduced by a bucket may occur in a well without handpump, but should not occur in a well with a handpump. Collecting information on the types of technology for which generic water safety plans will be developed would usually take the form of a detailed inventory of sources (Howard 2002; Lloyd and Helmer 1991).

The development of the generic technology water safety plans is usually best undertaken by a group of experts familiar with the technologies and the setting within the country. In Bangladesh a set of draft water safety plans were developed through convening a workshop of selected sector experts who went through the full process guided by facilitators familiar with water safety plans (APSU, 2005). The outputs from the workshop were a set of generic water safety plans for use by organisations undertaking the rolling-out of water safety plans to community-managed water supplies. The water safety plans themselves were not provided to the community, rather a set of simplified tools for community operators were developed to support action-orientated monitoring.

Water safety plans for can be based on the results of studies of water quality and sanitary inspection on a representative sample of water supplies throughout the country that reflect different climatic and hydrogeological conditions (Howard, 2003). Hazardous events that affect particular technologies, the likelihood of their occurrence and the impact of water quality can be assessed through simultaneous collection of sanitary inspection and water quality data. The process followed is also a form of validation of the protection barriers put in place around a small water source to secure water safety.

Sanitary inspection forms should be used to undertake the hazardous event assessment. These may initially identify a long list of questions to be asked regarding the security of the source, which through piloting and review of data may be reduced to key questions that apply for all sources of the same technology. The material shown in Appendix C provides examples of the types of forms that may be developed. These forms include a range of factors that can be broadly categorised into three groups (Howard 2002):

- Hazard factors – these are potential sources of faeces situated so that they may represent a risk to the water supply (an example being the location of a pit latrine in relation to the water source).
- Pathway factors – these are potential routes by which contamination may enter the water supply (examples include eroded backfill areas of protected springs, or leaking pipes).
- Indirect factors – these are factors that represent a lack of a control measure to prevent contamination (and therefore increase the likelihood of a hazard or pathway developing), but do not themselves represent either a hazard or a pathway. An example of this is a fence around the water source. The absence of a fence will not lead directly to contamination, but may allow animals or humans to gain access to the source and create either a hazard (through defecation) or a pathway (through causing damage to the source or its immediate surroundings).

In many cases the presence of multiple factors may be required in order for contamination to result, based on a source-pathway-receptor model that is commonly used to explain contamination. There are likely to be exceptions to this general rule, for instance where a particular hazard is the sole cause of the contamination (Lloyd and Bartram 1991). In such a case, while reductions in other risks may be desirable, they may potentially have limited impact on the quality of water (Howard 2002).

13.3.1 Designing the studies to develop water safety plans

Variability may be significant for both microbial and chemical quality. For instance, in rural areas peak microbial contamination may occur at the onset of a wet season, but then rapidly diminish as the reserves of faecal material are exhausted (Bartram 1999). In peri-urban areas, microbial contamination may occur in response to a rainfall event, but as the faecal reserve is not exhausted repeated peaks may be found (Howard *et al*. 2003).

Studies to support the development of water safety plans can be undertaken in several ways. Longitudinal studies require repeated sampling of the same sources over an extended period, with one year being a realistic minimum to gain a sufficient set of data to represent variation in quality. If these studies are undertaken then the collection of rainfall data is strongly advisable. Cross-sectional studies may also be used, which will typically involve single samples taken from a wider range of sources.

These have an advantage in that a much wider range of sources may be visited which may increase representivity in relation to the source characteristics, but will not provide information regarding seasonal fluctuations in quality. If data are also collected on rainfall then some indication of the impact of rainfall may be possible.

The final method is to review data available from routine monitoring programmes, whether in their entirety or a sample of results. This approach may provide a mixture of data from repeated sampling from the same sources with single samples taken from sources, which may add to the complexity of the analysis of the data.

Analysis of the data from the studies is important in understanding the relative importance of different hazardous events and in the interactions between risk factors that lead to contamination occurring. This allows both the identification of specific control measures and also provides a greater insight into how different possible hazardous events may occur. Statistical analysis may be based on simple assessments of frequency of reporting of sanitary risks (Cronin et al, 2002) or through the use of contingency tables and logistic regression (Howard et al, 2003).

References:

APSU, 2005 'Support to implementation of water safety plans, www.apsu-bd.org

Cronin A, Breslin N, Taylor RG and Pedley S, 2002, Assessing the risks to groundwater quality from on-site sanitation and poor sanitary well completion, in 'Eocsan- closing the loop', Proceedings of the Second International conference of Ecological Sanitation, Lubeck, Germany, April 2003.

Howard G, Pedley, S, Barrett M, Nalubega M & Johal K. (2003). Risk factors contributing to microbiological contamination of shallow groundwater in Kampala, Uganda. Water Research, 37(14): 3421-3429.

13.1: Contingency table analysis of water quality and sanitary inspection data (adapted from Howard *et al*. 2003)

Variable	Faecal streptococci >0 cfu/100ml			Thermotolerant coliforms >10 cfu/100ml		
	Odds ratio	p	95% CI	Odds ratio	p	95% CI
Faulty masonry	1.913	0.008	1.185-3.087	1.506	0.075	0.960-2.363
Backfill area eroded	2.276	0.001	1.381-3.749	2.762	<0.001	1.716-4.445
Collection area floods	0.966	0.890	0.591-1.579	0.603	0.035	0.377-0.964
Fence absent or faulty	5.175	0.052	0.987-27.138	3.496	0.138	0.668-18.303
Animal access <10m	2.010	0.488	0.279-14.471	1.366	0.756	0.190-9.826
Surface water uphill	3.655	<0.001	2.054-6.507	3.933	<0.001	2.316-6.680
Diversion ditch faulty	1.114	0.679	0.667-1.862	1.324	0.263	0.810-2.163
Other pollution uphill	2.040	0.259	0.577-7.210	5.728	0.029	1.196-27.429
Latrine <30m uphill of spring	1.229	0.455	0.715-2.113	1.759	0.036	1.038-2.979
Latrine <50m uphill of spring	0.862	0.547	0.532-1.397	0.738	0.198	0.465-1.171
High population density	2.889	<0.001	1.780-4.688	4.708	<0.001	3.899-7.644
Waste <10m uphill of spring	0.144	0.150	0.875-2.380	2.557	<0.001	1.560-4.189
Waste <20m uphill of spring	1.340	0.231	0.830-2.163	3.085	<0.001	1.923-4.950
Waste <30m uphill of spring	0.842	0.590	0.451-1.573	1.896	0.031	1.059-3.397
Rainfall within previous 5 days	2.284	0.009	1.225-4.259	4.097	<0.001	2.096-8.008
Rainfall within previous 2 days	3.285	<0.001	2.014-5.357	3.827	<0.001	2.385-6.139
Rainfall with previous day	2.583	0.001	1.473-4.529	2.115	0.004	1.276-3.506

Table 13.2: Generic water safety plan for protected spring not connected to a piped network

Hazardous event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action	Verification
				Target	Action	What	When	Who		
Contam. able to recharge spring in backfill area	Backfill area becomes eroded	Mod/ major	Effective spring protection measures maintained	Area has grass cover; fence and diversion ditch in good condition No surface water uphill	Fence is broken Diversion ditch is damaged Surface water pools develop	Sanitary inspection	Monthly	CO	Repair fencing and ditches; drain surface water. Re-lay grass. Rehabilitate protective measures	Sanitary inspection and analysis of: *E.coli* and faecal streptococci
Contamination in spring box or outlet	Spring box or retaining wall in poor condition, inund^{n} from ww	Mod/ major to mod	Maintain protection and drainage works	Masonry in good condition; ww ditch clear and in good condition	Masonry deteriorated; ww ditch blocked	Sanitary inspection	Monthly	CO	Repair masonry and covers; clear ditch	Sanitary inspection and analysis of: *E.coli* and faecal streptococci
Contam. surface water causes rapid recharge	Surface water is allowed to form pools uphill and leads to rapid recharge of pollutants and limited atten^{n}	Mod to un/ major	Establish set-back distance based on travel time; drainage	No surface water, solid waste dumps uphill Faecal disposal methods available	Surface water close to springs Low sanitation coverage Poor solid waste removal Springs show rapid response in flow and quality to rainfall	Sanitary inspection Colour change response to rainfall	Monthly/ seasonally	CO	Drain surface water pools uphill of springs, promote improved sanitation and solid waste disposal	Sanitary inspection and analysis of:*E.coli* and faecal streptococci

Hazardous event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action	Verification
				Target	Action	What	When	Who		
Ingress of animal faeces	Animal husbandry uphill and close to the spring Animal damage to backfill area	Mod/ mod	Set-back distance to Control animal husbandry; good fencing	No kraals or sheds in set-back distance; fence in good condition	Animal husbandry found within controlled area Fencing damaged or absent	Sanitary inspection	Monthly	CO	Remove animal sheds or kraals from uphill of spring or move to safe distance Repair or erect fences	Sanitary inspection *E.coli*, faecal streptococci, bacteriophages, nitrate
Leaching of microbial contaminants into aquifer	Leaching of faecal material from sanitation, solid waste, drains	Mod/ mod	Provide adequate set-back distances defined on travel time	No sources of faecal material within set-back distance	Latrines/ sewers built or solid waste dumps within separation distance	Inspection by community	Monthly	CO	Move pollutant sources, improve sanitation design, reduce sewer leakage	Sanitary inspection *E.coli*, faecal streptococci, bacteriophages, nitrate, chloride, tracer studies
Leaching of chemicals into groundwater	Leaching of chemicals from landfills, waste dumps, discharges to ground	Mod/ minor	Provide adequate set-back distances defined on travel time	No sources of chemicals within set-back distance	Pollutant discharges within set-back distance	Inspection by community	Monthly	CO	Move pollutant sources, improve pollution containment	Inspection Analysis of chemical composition of pollution Analysis of water quality

Contam. – contamination; Mod – moderate; Un – unlikely; inund^{n} – inundation; atten^{n} – attenuation ; ww – wastewater; CO – community operator

13.3.2 Implementing a system of support for generic technology water safety plans

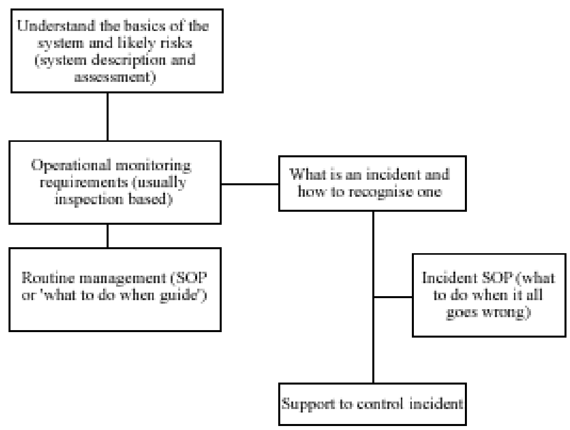
Once the generic technology water safety plans have been developed, the water safety plan team will need to develop a strategy for rolling-out implementation of the water safety plans at a source level. This will require the development and testing of simple monitoring and operational tools for community operators, development of training materials and a programme of ongoing support and surveillance. These tools should be piloted in a small number of communities, evaluated and refined before trying to roll-out a programme across a country.

Responsibility for ensuring water safety and implementing a water safety plan in a community-managed supply resides with the operator of the supply who, by using tools for monitoring and maintaining control measures, should have the skills and resources to ensure that the relevant generic technology water safety plan can be applied. Ensuring that the operators have adequate skills and capacity to perform this role is a critical aspect of the effective implementation of a water safety plan. This requires that the tools developed for community operators are easy to use and provide the operator with information for each control measure, such as:

- what the control measure is and how it prevents or reduces contamination;
- how the performance of the control measure is measured and what monitoring tools should be used;
- how often monitoring should be undertaken and how information will be recorded;
- to identify when the control measure has exceeded a critical limit; and
- to apply the appropriate corrective action when a critical limit has been exceeded.

Performing these tasks successfully requires that the operator is provided with the appropriate technical training and materials as shown in Figure 13.1.

It is also important that operators are aware of the agency to contact should a problem be noted that is beyond their immediate capacity to correct. In addition to operator training, training should also be provided to a water management committee to enable them to monitor the performance of the operator. This should include development of simple reporting formats between the operator and the management committee and establishing agreed targets and milestones. Where an operator is deemed to consistently fail to provide the level of performance expected or is no longer available to carry out the tasks required, the committee should have a means by which to bring this to the attention of the support or surveillance agency. This may result in identifying and training a new operator. As the maintenance of water safety requires ongoing interventions ongoing training of the operator, by an external agency, is likely to be required. Thus the surveillance or support agency may wish to develop local training units or contract reputable third party organisations to support ongoing skills development and training provision.



SOP – standard operating procedure

Figure 13.1: Community operator requirements for water safety plan implementation

The first component of the water safety plan is a simplified guide to the technology that should provide the operator with a basic description of the technology, how it works, how it prevents or reduces contamination and what problems could occur that would result in contamination. This guide should provide the operator with a good understanding of their system and how their activities are important in controlling risks. The use of illustrations is likely to be important in all circumstances and in particular for operators of very small systems in developing countries.

Community operators will also need simple tools for monitoring of the control measures and actions to be taken when the control measures are no longer in compliance with critical limits. Monitoring of the control measures can largely be achieved through regular sanitary inspection. This should use approaches that are closely linked to actions to be taken as a result of monitoring data indicating that a critical limit is being exceeded. Either pictorial or written forms may be appropriate depending upon the level of literacy. In both cases, however, it should be clear what is action is expected when the monitoring indicates a loss of control measure compliance. Example forms are shown in Tables 13.3 and 13.4.

Table 13.3 Community checklist for monitoring a protected spring

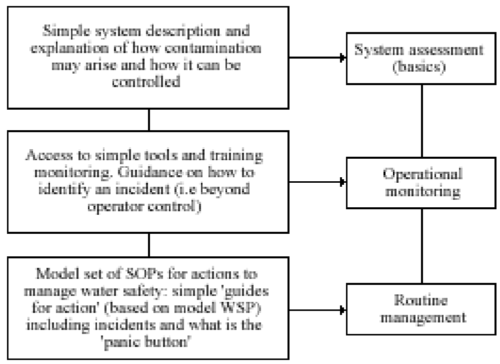
Checklist	No	Yes	Action
Does the water in the spring change colour after heavy rain?			
Have the local public health department tested your spring recently?			
Were you told the result and given any advice?			
Did you act on the advice?			
Is the retaining wall showing any signs of damage?			
Does the retaining wall need repair – what is this and can you do it yourself?			
If you cannot do it, is there anyone in your community who can do this repair?			
How much will the repair cost (think about labour as well as material)?			
Does the uphill diversion ditch need cleaning?			
When was it last cleaned?			
Is the drainage ditch below the spring blocked or need clearing?			
Does the fence need any repairs?			

In some circumstances it may be more appropriate to use pictorial approaches to illustrate what constitutes good and bad practice regarding water safety management. The latter can draw on examples from the Participatory Health and Sanitation Transformation (PHAST) approach to hygiene, which contains examples of the types of materials and their use in relation to water source management (WHO 1996b). The approach adopted should be based on the needs and capacity of the communities that will use the generic water safety plan within the country.

Table 13.4 Checklist for operation and maintenance of a protected spring

Activity	Dry season	Wet season		Action limits
		Routine	After heavy rainfall	
Clear uphill diversion ditch	At least once per month	At least once per week	Always inspect	Clean if ditch contains mud or silt
Clear drainage ditch from outlets	At least once per month	At least once per week	Always inspect	Clean if ditch contains mud or silt
Slashing grass inside fence	At least once per dry season	At least once per month		Cut grass once it exceeds mid-shin height
Make sure steps are clean and not broken	At least once per week	At least once per week	Always inspect	Clean and repair when dirty or showing signs of breaking
Clear rubbish away from area around spring, particularly uphill	At least once per week	At least once per week	Always inspect	Dispose of rubbish properly
Keep paths and grassed areas above springs clear of rubbish	At least once per month	At least once per month		Clear paths and dispose of rubbish properly
Trim hedge once it reaches a height of 4 feet	Do not trim in the dry season	As soon as hedge reaches 4 feet in height		Trim hedge
Carry out regular inspections of the spring and note any faults	At least twice per week	Daily	Always inspect	Record faults and identify actions to be taken

The materials and tools required by operators to implement a generic water safety plan are summarised in Figure 13.2 below.



SOP – standard operating procedure
WSP – water safety plan

Figure 13.2: Providing the information to the operator

13.3.3 Developing supporting programmes

A programme of support and surveillance will need to be developed to aid implementation of the generic water safety plan. It is important that these programmes reflect the capacity of the surveillance agency and are piloted to ensure the long-term applicability. The stages and requirements to achieve this are outlined in Figure 13.3.

Pilot trials of the water safety plans should be undertaken in a number of communities to evaluate their effectiveness and to identify modifications required. The pilot should run for at least 12 months and be evaluated to ensure the monitoring tools have been used and appropriate actions taken. The evaluation should also include an assessment of the feasibility of the supporting programmes.

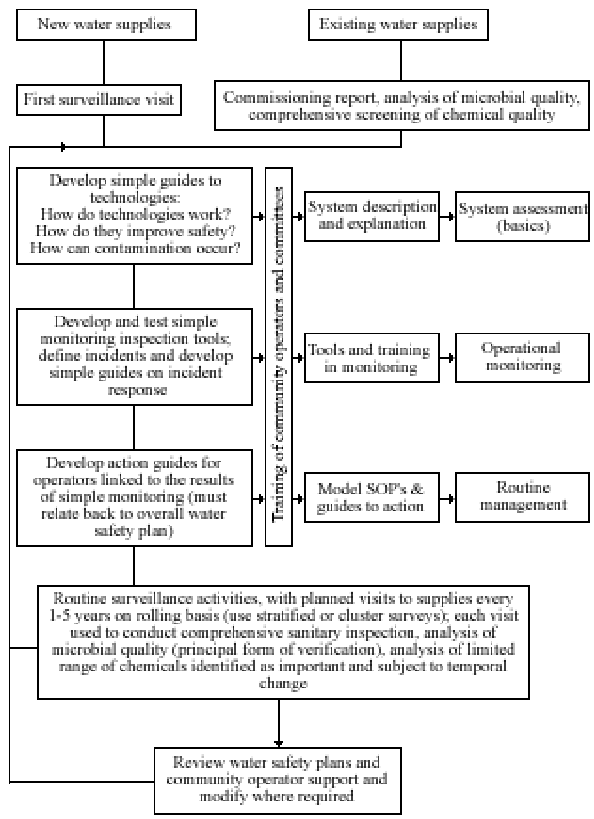


Figure 13.3: Implementing the water safety plan roll-out

Implementing a generic technology water safety plan includes several key elements. These include the development of training and supporting materials that will enable the community operator and other key members of the community (for instance water committee) to operate the water safety plan, undertake the required monitoring and understand how the data will be used. The development of a monitoring programme by the community will require training for the community water supply operators.

13.3.4 Progressive expansion

The progressive rolling-out of the water safety plans requires careful planning and will almost certainly have to address the two different situations of new supplies being developed and application of water safety plans to existing water supplies. It is recommended that programmes be developed for both situations, with training and support to water safety plan development in all new supplies that are developed and a programme to provide training and support to implement water safety plans in existing supplies prepared.

A water safety plan should be developed for all new supplies with appropriate training, tools and documentation provided to operators before the supply is commissioned. This should be supported by testing of samples of water taken from the source as part of a commissioning report. The selection of chemicals to be included should be based on an assessment of the natural chemicals and pollutants likely to be present, based on the geology, climate and land-use. Further guidance is available in Thompson *et al*. (2004) for inclusion in drinking-water quality monitoring programmes.

The existing supplies are likely to represent a larger group than the new supplies and thus the programme will need to consider the most effective approach to developing appropriate water safety plans and associated support programmes. This will be most effectively done through the progressive rolling-out across the country/region.

The roll-out of generic water safety plans could be integrated into the development of a regional surveillance programme. In terms of planning, it is important that the rolling-out takes into account the capacity of the surveillance agency and water supply agency/authority to provide ongoing support to communities. Experience from a number of countries has shown that to have an impact on the quality of small water supplies, surveillance programmes must be directly linked to interventions (Bartram 1999; Moore 1999). Therefore investment to support water safety plans should be linked to investment in order to support development of surveillance at local levels.

13.3.5 Verification for generic technology water safety plans

Responsibility for the verification for generic technology water safety plans should not be undertaken by the community operator, although they should participate in the process. The verification of performance will primarily be carried out by the surveillance agency as part of their routine activities. Verification should focus attention on the overall microbial quality of the drinking-water and will also include testing of those chemicals previously identified as locally or regionally important. Although it will be expected that the principal faecal indicator organisms used will be *E.coli* or thermotolerant coliforms, a limited number of analyses of other organisms such as faecal streptococci and bacteriophages may also be included. Such analyses would be expected to be performed on a smaller number of supplies and form specific targeted assessments rather than broader routine surveillance.

It is unlikely that verification will occur at every small supply on a frequent basis as the costs involved in regular visits and testing are prohibitive in most countries. Therefore, verification should be designed as a means of assessing the performance of the generic technology water safety plan as applied across a number of water supplies rather than assessing the performance of its application on individual supplies. If this approach is adopted then only a sample of supplies using the generic water safety plan need to be visited each year. It would be expected, however, that each supply would be visited regularly, for instance once every three to five years.

13.4 GUIDES TO AID LOCAL DEVELOPMENT OF WATER SAFETY PLANS

For many smaller communities (including where utilities operate a small town supply), there may be a lack of capacity to undertake the development of a system-specific water safety plan without external support, but where applying a generic technology water safety plan would not be appropriate. This may be because the system is relatively complex and there may be significant variation in the hazardous events that could affect supplies. These situations would typically apply in larger communities with a well-defined management structure, with more than one operator who may receive partial remuneration and commonly where some form of piped distribution system exists.

In such situations, the development of a water safety plan can be tailored to the situation found in the supply but based on a set of generic materials that provide guidance in developing the water safety plan. To support the local development of water safety plans for small systems, a number of supporting materials are required. These will typically include guidance notes, for instance in the form of flow charts and decision-trees for different components of water supplies. Demonstration materials or example plans may be required to provide users with a clearer idea of what is contained within a water safety plan and how they are structured and used. These should provide the local water safety plan team with information regarding the type of hazardous events that may occur and examples of potential control measures with associated monitoring, critical limits and means of verification. The model water safety plans included in the Appendix illustrate the type of an example material that could be provided, in addition to guides to support local water safety plan development. In developing guides on the preparation of the water safety plans, a national team of experts with extensive experience of small water supplies should be established to develop both the guides and model water safety plans.

The first stage in developing the guides and model water safety plans is to decide what types of supply will be targeted. Implementation is likely to be easier to plan and manage if a clear distinction is drawn between the types of water supply or community where generic technology water safety plans should be used and those that will be expected to develop system-specific water safety plans using guides and model water safety plans. Clear criteria should be established, for instance in relation to technology type, management arrangements and population size. Some possible criteria are as follows:

- treatment is applied within the water supply (including where only terminal disinfection is used routinely);
- the water supply has a piped distribution system that serves more than a few public taps;
- the population served by the individual supply exceeds 1000 people;
- the supply has more than one operator, who receive some payment for services provided; and,
- there is distinct management body with a constitution.

In order to achieve the local development of water safety plans for small systems, the operators will need a range of information as outlined in Figure 13.4.

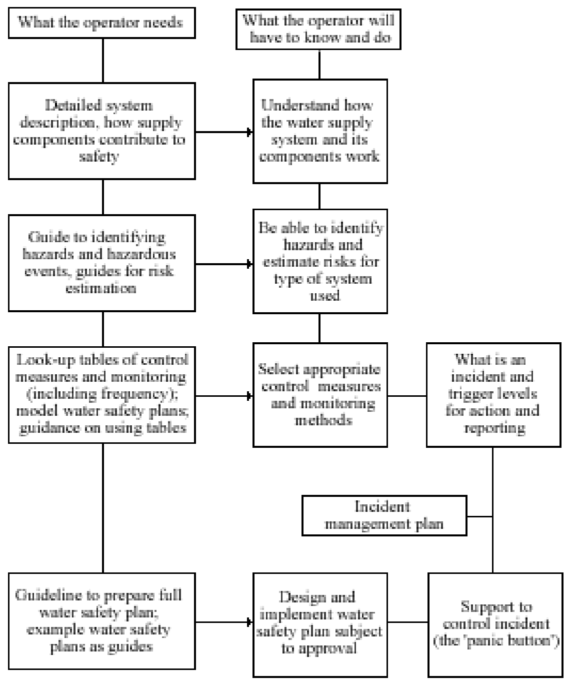


Figure 13.4: Supporting guided water safety plan development and implementation

13.4.1 Preparing the support material

Developing descriptions of water supplies and their components is the first stage of this process. These descriptions should be more extensive than those developed for the generic water safety plan materials and be in the form of simple booklets covering the scientific and engineering principles of each component of the system. This should include discussion of how the different parts of the system act to control risks by ensuring that hazards are reduced, eliminated or excluded from the water supply. The descriptions can be 'modular' to allow operators to develop a set of materials dealing with their own system. The modules should cover source protection, water treatment and distribution.

Material should also be developed to support operators in undertaking hazard identification (primarily in terms of hazardous events), risk assessment, identifying control measures with associated critical limits and monitoring. These guides should provide the user with clear guidance regarding how to identify a potential hazardous event and to determine the risk of that event occurring. Guidance should also be provided to the users about appropriate monitoring for each control measure, which is likely to be a mixture of inspection methods and physico-chemical tests. This guidance is best provided in a series of look-up tables including, for instance, a number of potential control measures and the appropriate monitoring approach. The information included in the model water safety plans in the Appendix could be used as a starting point to develop these look-up tables.

As with the development of the generic technology water safety plans, the guidance material (including model water safety plans) should be developed by a national team of experts with detailed knowledge of the types of supply that will be covered and the types of hazardous events and control measures that will be effective.

It is important that in developing the model water safety plans, that the risk of hazardous events is based, wherever possible, on analysis of water quality and sanitary inspection data, potentially through failure analysis or through the development of statistical models. The model water safety plans should be based on analysis of representative data and should ensure that weighting of the likelihood of the event occurring reflects data from the field. As with the approach to developing the generic water safety plans, such analysis can be based on data derived from specific assessments designed to be representative. Data previously collected should also be analysed to provide a longer-term perspective on risks that may arise.

The model water safety plans should be similar in format to the expected structure of a water safety plan and provide the user with a comprehensive list of likely hazardous events, control measures and means of monitoring. In approaches used in New Zealand, potential hazardous events and control measures are listed for water supplies, with local operators expected to identify those hazardous events and controls that can be put into place in their supply (NZMOH 2001). It would also be possible to provide a full model water safety plan to users and encourage operators to select those that are of relevance to their system. It is important, however, to ensure that users do not simply copy the model water safety plan but use these in conjunction with the advice within the guides to develop their own water safety plan.

13.4.2 Developing and testing the guides

The guidance material may take a number of forms including manuals, videos, audio-visual material and web-based guides. The guides should provide sufficient information to allow users to follow the process and should refer to model water safety plans. The guides should be structured so that the user is taken through all the stages of the establishment and implementation of a water safety plan. The use of decision-trees and flow-charts is particularly helpful and the guides should provide questions to prompt the user to identify information needs and how to acquire this information. The guides should assist the user in making key decisions, for instance regarding the selection of particular control measures or the frequency of monitoring or verification that will be required.

The team developing the guidance material should include water quality specialists but will also be likely to benefit from participation from professionals within the knowledge transfer sector. The success of the guides may rest, to a significant extent, on the degree to which the guides are user-friendly and use a language and approach that is comprehensible to the target audience.

Before embarking on a programme of guided water safety plan development, the materials within the guides and model water safety plans should be piloted and evaluated. Where additional training is to be provided to operators this should also be piloted and evaluated to ensure that the materials prepared will result in effective water safety plans being developed.

13.4.3 Approval of the water safety plan

The water safety plans developed based on guidance material should undergo a formal approval process. This will require that an external assessor (either the surveillance agency or accredited third party organisation) review the water safety plan and water supply to ensure that there are no omissions and that the water safety plan in its entirety will provide assurance of safety. Such a process requires a detailed assessment of the catchment and source, an audit of the treatment works and field assessment of the distribution systems. Where the water safety plan in deemed to be inadequate for a particular supply, the assessor should identify deficiencies in the plan and make recommendations for improvements. If there is a persistent failure by the community water supply managers to develop an appropriate water safety plan, the surveillance agency should have the right to impose a water safety plan on the supply managers.

13.4.4 Verification

Where the process of establishing a water safety plan is being guided in the fashion outlined above, how verification is undertaken should be carefully considered. In some situations it may be possible for the system operators to undertake some verification using low-cost analytical equipment. This would primarily focus on the analysis of water quality, with principal focus on *E.coli* or thermotolerant coliforms and chemical hazards of concern. Verification programmes will need to be undertaken regularly and the surveillance agency should support and approve local verification programmes.

In this situation, the surveillance agency will still be required to conduct additional analysis of the water quality, including assessments of a wider range of indicator organisms and chemicals, and undertake audits of the systems. In other cases, primary responsibility for verification may devolve to the surveillance agency as in the case of the technology generic water safety plans. Whether verification is performed by both the operator and surveillance agency or surveillance agency alone, the primary objective of verification is the performance of the water safety plan for individual supplies, with broader lesson-learning a secondary objective.

13.4.5 Progressive expansion

The use of the guides for the development of water safety plans is likely to require progressive expansion, although it can be expected to be quicker than for generic water safety plans as the requirements on supporting bodies may be more limited and greater use can be made of a range of audio-visual tools to support development. Guided water safety plans should be prepared and supported for all new supplies constructed and training provided to operators before they take up their responsibilities.

For existing supplies, the roll-out may be more progressive and could be integrated with the surveillance programme or other means of support to smaller water supplies. It is likely that progressive rolling-out of the programme can be achieved relatively quickly and should follow either administrative boundaries or supply types – for instance, small towns supplies first followed by increasingly smaller communities.

14

Water safety plan review, approval and audit

An appropriate body, usually the regulator or their designated agents, should review and approve water safety plans prepared by suppliers or Government agencies. This process is designed to ensure that the water safety plans developed are consistent with the water safety requirements articulated within the health-based targets. The review process is essential in the overall implementation and links to ongoing audit by providing the basis from which future assessments can be based.

14.1 INTRODUCTION

Undertaking a systematic technical review of the water safety plan is based on the assessor using a range of materials. In particular the review team will be expected to review the documents provided by the supplier, to undertake field investigations, to interview and question the water safety plan team and to review material from similar supplies and best-practice guidance.

The review process should come to one of the following conclusions:

- Water safety plan is approved in full and is ready for implementation. This approval would be time-bound and a date for the next review would be set at this time (usually 2-5 years from the initial review);
- Water safety plan receives provisional approval and can be implemented subject to ensuring identified information gaps are filled. In this situation the water safety plan would be likely to adequately cover most areas of concern in delivery of safe drinking-water, but may have some gaps in knowledge, for instance because there remains a lack of research. Provisional approval allows implementation, but should set time limits for the resolution of identified problems.
- Water safety plan is rejected as inadequate and the supplier is required to go back and develop a new water safety plan. This situation would only occur when the supplier had failed to cover the major issues for which knowledge is adequate to establish a water safety plan or has failed to employ sufficient staff to implement the water safety plan. Failure should be linked to a requirement for a re-submission or, if there is repeated failure, for the imposition of a water safety plan by the review team.

14.2 IMPLEMENTATION, HUMAN RESOURCES AND DOCUMENTATION

The first stage of the review should be to evaluate whether an appropriate water safety plan team has been established, with allocation of responsibility for specific tasks and an overall water safety manager who is responsible for the delivery and implementation of the water safety plan. In addition, the full water safety plan should be appropriately documented, with supporting materials available that provide justification for decisions and which provide an outline of the work undertaken and the work proposed. It is very important that this material is available for review and if any documentation is lacking, the assessor should ensure that the supplier provides this before the water safety plan is approved.

The documentation should typically contain:

- A system assessment that provides an indication of whether the health-based targets can be met.

- The detailed water safety plan, including identified hazardous events and their location within the system, proposed control measures with associated monitoring and critical limits and details of corrective actions.
- Monitoring plans should be provided as an annex to the water safety plan and provide justification for the selection of parameters (including where available the relationship between the parameter and issues of health concern) and the frequency of monitoring.
- A verification plan for the water safety plan showing sampling programmes, parameters selected and justification of the selection of verification approaches in relation to demonstrating that the water safety plan will comply with the health-based targets.

14.3 EVALUATING THE SYSTEM ASSESSMENT

During the system assessment stage, the water supplier is expected to review the source water quality, the protection measures put in place, treatment process applied and distribution management in order to evaluate whether the health-based targets can be achieved. Most typically, it would be expected that for all processes of drinking-water production the expected reductions in pathogen or chemical concentration that are achievable will be documented and that for processes of distribution an evaluation made of whether risks will increase due to ingress of contaminated water. In reviewing the system assessment, therefore, a judgment is made as to whether the expected performance of the production processes and distribution maintenance processes are realistic.

This may be carried out at different levels of reliability and accuracy and this is important to consider when undertaking the review. The optimal system assessment is one where the water supplier has collected data on pathogen occurrence within the source waters and has made systematic evaluations of the reductions of organisms through source protection or treatment processes using either pathogens or accepted indicator organisms. This data will then have been used in a risk assessment to define whether the performance targets achieved result in a level of risk that is tolerable. This may be carried out following the more comprehensive approach outlined by Havelaar and Melse (2003) or the simplified approach outlined in the third edition of the *Guidelines for Drinking-water Quality*, (see also Chapter 12). The supplier should have also undertaken an assessment of the quality of water within the distribution system and made a risk assessment based on available data. By preference, this will be based on data collected on pathogens or indicator organisms from within the distribution system.

All the risk assessments, with any limiting assumptions that were made, should be presented as part of the documentation dealing with the system assessment. It is important that the supplier demonstrate at least some understanding of the public health consequences of poor system design and operation. The review of a quantified risk assessment should only be undertaken by an assessor with knowledge of such approaches. The review should assess whether the data presented is of sufficient depth and breadth to support the conclusions drawn, whether appropriate quality assurance and control procedures were followed and whether seasonal or other influences were taken into account in the survey design. For the risk assessment calculations, the source of information on aspects such as dose-response and population exposed should be documented and the assessor must assess whether these are reliable or whether there are local circumstances that may alter any of the assumptions made. Where data has been generated locally through public health assessments the study design should be evaluated and the data presented should be reviewed in order to satisfy the assessor that appropriate conclusions were drawn. This may involve review of data from other sources as a mean to compare locally generated data.

In some cases there may be a lack of quantified data on the system concerned. In this case, a more theoretical approach can be adopted, although the level of limiting assumptions will reduce the confidence that can be placed in the results. Theoretical approaches include the allocation of log-reduction credits to treatment processes, an approach that has been employed in a number of countries and which is based on research literature outlining the expected removal of pathogens or chemicals (see Chapter 12 and LeChevalier and Au 2004). Such approaches are valid in that they still attempt to provide an indication of the expected removal and can therefore be used as a planning tool to determine whether additional investment is required to upgrade the system. However, there are significant limitations on this approach because the allocation of credits may not take into account operational weaknesses that lead to lower than expected reductions. If theoretical approaches are adopted, it is worth considering making at least qualitative estimates of failures both within production and distribution facilities as a means of capturing likely operational failure (Westrell *et al*. 2003).

The review of a theoretical system assessment should focus on a number of issues, namely:

- are the expected source water concentrations reasonable assumptions;
- are the allocated log-reduction credits reasonable assumptions; and
- are the sources of these assumptions provided?

This is important, as such approaches rely heavily on the use of credible and valid scientific research. By preference, source material should be drawn from the peer-reviewed domain to provide some additional confidence in the results. If data is drawn from non peer-reviewed sources, then additional caution should be taken in signing off the system assessment. In this case, the assessor may demand that the supplier undertake a systematic review of the literature and repeat the system assessment using this as the basis.

14.4 HAZARDOUS EVENTS

The review of hazardous events requires two critical questions to be asked:

- are the hazardous events described credible within the system under consideration;
- are there any hazardous events that have been omitted that should have been included?

In order to answer these questions, the assessor should look at all the material presented on the nature of the system and the environment that surrounds it and decide whether the hazardous events appear reasonable or whether any may have been overlooked. The assessor should use experience from other systems within the country or documented in the literature to evaluate the hazardous events presented. It is also important to undertake at least some field work to visit parts of the system and request that the water safety plan team describe how the hazardous events they propose could occur. This may also provide the team with an opportunity to explain why particular severity or frequency categories have been allocated to hazardous events and to explain why, in their opinion, some hazardous events could not occur in their system. In the latter case, it is not acceptable for the team to use good operation as a justification, as this would logically appear within the water safety plan as a control measure. Rather, exclusion should be on the basis that either the source of hazard does not exist, that no pathway to the water source could occur or that it would be impossible for the hazard to gain entry.

Where the assessor identifies either a lack of credible evidence for identified hazardous events to occur or that credible hazardous events have been omitted, there should be a requirement placed upon the water supplier to address these within a specified time frame. In usual circumstances, the supplier will either be expected to remove or add the hazardous events identified or provide convincing evidence that there should be no change. Approval during the review process should be dependent on the water safety plan providing a full and comprehensive list of credible hazardous events that could affect the supply. If this cannot be demonstrated then the water safety plan should not be approved until such time as the hazardous events are revised.

14.5 EVALUATING CONTROL MEASURES

The evaluation of control measures lies at the heart of an effective water safety plan and is critical to ensuring that the water safety plan developed can be approved as adequate. If no control measure is proposed to control a hazardous event, the water safety plan cannot be approved and the supplier must be required to develop proposed control measures for the event. If control will require a significant upgrade, then interim controls that will help reduce the impact of the hazardous event should be identified, while a longer-term plan is being developed to provide control.

The control measure put forward to deal with identified hazardous events must be credible and supported by evidence from the supplier. This may take the form of scientific research undertaken or commissioned by the supplier on the water supply or similar supplies that they manage or may be taken from the scientific literature. If evidence is not presented by the supplier, then the assessor may require that this be found before the water safety plan is formally approved. This may therefore result in the water safety plan being only provisional in the first instance with an agreed process by which the evidence will be obtained and presented.

When evaluating control measures, the important question to answer is whether the proposed measure would prevent the hazardous event from occurring. To do this, the assessor must be satisfied that the control measure will do one (or sometimes more) of the following:

- remove the source of hazards from the environment within an area that could feasibly affect the water supply (an example is the prohibition of sanitation facilities or animal feedlots within specified distances of water sources);
- act to reduce the concentration of hazards to acceptable levels (examples being treatment processes);
- prevent hazards from leaving the hazard source and entering the water supply (an example would be the use of a cut-off wall between a sewer and a water supply main that effectively prevents direct movement between the two); and
- prevent entry into the water supply (examples being wellhead completion or pipes with no leaks).

If the water safety plan does not provide adequate evidence regarding the control measure or if the assessor considers the control measure to be inadequate to provide protection of water safety, then the water safety plan cannot be fully approved and the supplier must be required to revise or develop new control measures. Much of the evidence presented should be derived from validation exercises. Where information is lacking (which may occur in many situations) the water safety plan should identify this and refer to a plan of validation and research.

14.6 MONITORING AND ESTABLISHED LIMITS

The review should also assess whether the proposed means of monitoring for each control measure is appropriate, whether the established limits (operational and critical) are appropriate and whether the monitoring plan is adequate to ensure that sufficient data will be collected to demonstrate that the control measure is in compliance.

The water safety plan team should present evidence to support why the means of monitoring is appropriate for the control measure. This need not be a lengthy discussion, but the team should provide a basic short description. This may be drawn on experience or the literature. The monitoring plan should also be reviewed to assess whether the proposed frequency of data collection is sufficient. This relies on an assessment of how rapidly it can be expected for the control measure to change and the severity of the resulting risk. Any control measure that would result in major or catastrophic results should have frequent and preferably on-line monitoring.

Reviewing monitoring relies heavily on expert judgement in relation to the specific control measures. In general terms, however, control measures that relate to *processes* (e.g. treatment) will tend to have monitoring that is more frequent and often on-line, whereas as those that relate to *measures* (e.g. source protection) will probably be less frequent and often be inspection based.

Equally, there should also be some justification of why the operational and critical limits have been set and evidence presented regarding whether these will provide adequate protection. The limits should be established such that remedial action can be taken to ensure the control measure is in compliance before a major health risk results. Evidence should be presented based on research undertaken by the supplier or from the scientific literature and the assessor should evaluate whether these sources are reliable and the results valid.

For some control measures and monitoring, there is ongoing work to define more precisely that relationship between monitoring parameters and likely pathogen concentrations, which will provide an improved basis for establishing critical limits. Where the supplier have undertaken such research themselves, this should be documented.

14.7 CORRECTIVE ACTIONS

The corrective actions provided for within the water safety plan should ensure that the control measure will be brought back into compliance and the review should therefore critically appraise each suggested action to see whether this would ensure control was re-established. The review should also assess whether the proposed action is the most efficient and effective.

In addition to measures that directly bring the control measure back into compliance, corrective actions may also be proposed that will avoid the delivery of unsafe drinking-water. An example being switching to an alternative source during the period of non-compliance. This will provide the operator with an opportunity to bring the supply back into compliance. If switching to an alternative source is included within the water safety plan, an approved water safety plan is also required for the alternative source. The absence of such a plan should lead the assessor to reject the corrective action.

The review should evaluate the evidence presented by the water safety plan team that the corrective actions conform to best practice by drawing on examples of water safety plans from other similar situations. If a corrective action is defined that is not part of best practice, the assessor should expect the water safety plan team to present evidence as to why the corrective action is appropriate, drawing on experience within the supply or the scientific literature as appropriate.

14.8 DOCUMENTATION AND REPORTING

The review should assess whether the supplier has put in place systems for documenting the activities in implementing the water safety plan, including results of monitoring and verification exercises. Clear lines of reporting should also be outlined and it should be clear from the water safety plan which staff within the water supply organisation will receive what information at what frequency and also what other organisations will receive information and when. A plan for appropriate documentation and reporting must be provided in order for the water safety plan to be approved. This is particularly important as implementation of the water safety plan should be audited and this therefore provides the basis for undertaking this activity.

14.9 VALIDATION AND RESEARCH

Some evidence should be presented in terms of validation within the control measures section. However, it is likely that there will need to be a process of ongoing research or validation to support decisions made to improve or maintain water safety. The review should take care to assess proposed validation/research plans. If none are provided, the assessor may bring this to the supplier's attention and request that such a plan be developed. Given the overall limited data on efficacy under operational conditions of many potential control measures, it is likely that some programme of information generation will be required and this should be considered as important as routine implementation.

14.10 VERIFICATION PLAN

The review will need to assess the verification plan for the supply to check whether appropriate tools and approaches are identified and that the frequency of verification exercises are suitable. The assessor will need a good understanding of the role and potential benefits of commonly used indicator organisms and operational audit tools in order to evaluate whether the verification plan will provide a reliable overview of the performance of the water safety plan.

Where the water safety plan team propose new methods of verification that do not match standard practice, there should be documented evidence to demonstrate that this approach is valid. Such documentation could, for instance, be based on the scientific literature or on research undertaken by the supplier. Where the means of verification has not been widely accepted (for instance because it applies a new method or an organism not commonly used) then the assessor may insist that the 'new' verification should be operated in parallel to the usual practice in order to have confidence in its use. Such a period of parallel implementation may last for several months or even years to ensure sufficient data is available.

14.11 AUDIT

Following review and subsequent implementation of the water safety plan, periodic audit of the plan is required. The frequency and timing of the audit procedure will vary according to circumstances and local regulations, but it should be conducted:

- at intervals (the frequency of routine audits will be dependent on factors such as the size of population served, and the quality of source water/treatment facilities);
- following substantial changes to the source, the distribution or storage system or treatment process; and
- following significant incidents.

Periodic audit should include the following, in addition to review of the water safety plan:

- examination of the records to ensure that system management is being carried out as described in the water safety plan
- ensuring that operational parameters are kept within specification and that compliance is being maintained;
- ensuring that verification programmes are operated by the water supplier (either through in-house expertise, or through a third-party arrangement) assessment of implementation programmes and development of strategies for improvement and updating the water safety plan; and
- in some circumstances, sanitary inspection, which may cover the whole of the water-supply system including sources, transmission infrastructure, treatment plants, storage reservoirs, and distribution systems.

In response to reports of significant incident, it is necessary to ensure the:

- the event is investigated promptly and appropriately;
- the cause of the event is determined and corrected;
- the incident and corrective action is documented and reported to appropriate authorities; and
- the water safety plan is reassessed to avoid a similar situation recurring.

The implementation of an audit-based approach places responsibility on the water supplier to provide the surveillance agency information regarding system performance against agreed indicators. In addition, a programme of announced and unannounced visits should be made by auditors to water suppliers to review documentation and records of operational practice to ensure data submitted is reliable. The surveillance agency will normally retain the authority to undertake some analysis of drinking-water quality to verify performance or enter into a third-party arrangement for such analysis.

15

Timescale and cost implications

This chapter provides an indication of how long it might be expected to take to establish a water safety plan. It also examines the likely cost implications; this is done through a series of examples drawn from supply experiences.

15.1 TIMESCALE

The time it will take to establish a water safety plan will depend upon a number of factors. These include:

- the experience of the staff;
- the amount of data available on the water supply;
- the size and complexity of the supply; and
- other systems that have already been adopted.

These factors are all inter-related and it is clearly difficult to define exactly what length of time is required to establish a water safety plan in all circumstances.

The experience of the team is critical, for instance one utility in Australia found that the time taken to prepare HACCP (Hazard Analysis Critical Control Point) plans (the systems from which water safety plans have been developed) for water supplies decreased as experience increased and found that the time taken reduced by approximately 50% with increasing experience with no decrease in the quality of the output. In Uganda, as staff became more familiar with data needs for water safety plan development and how the plan should be prepared, again the time input could be reduced. Similar experiences can be expected in most countries and water supplies when developing water safety plans.

The degree to which experience can reduce the time required to develop a plan will also depend on whether a dedicated individual or team are assigned to the project and how many other duties they must perform. In the longer term, internal auditing will also require a significant allocation of staff time to ensure that processes are being followed and actions taken to secure water safety.

The amount of data available is also an important factor. In water supplies where there are a lot of data on the supply, particularly the distribution system, the water safety plan is not only more comprehensive but it can be prepared more rapidly. Where data is lacking, the quality of the water safety plan may be compromised, necessitating additional data collection. In such circumstances, draft plans may be developed and linked to an ongoing process of improvement and data collection.

The size and complexity of the supply most obviously affects the time it is likely to take to put together a water safety plan. Large and complex systems, with more than one source, multiple treatment works and/or large and complex distribution systems will inevitably require a greater time input than small, simple systems. However, at the same time larger systems typically have more comprehensive data on the supply and more skilled staff and therefore although the time taken may be greater, if calculated on a per capita or volume of water produced the plan preparation may be more efficient.

The experiences of Gold Coast Water (GCW) in putting together their HACCP plan are outlined in Box 15.1. GCW operates several thousand kilometres of water main with 74 storage tanks and two water treatment plants, serving a population of 450,000 in Australia. The company had already achieved ISO 9000 and their experience in implementing their HACCP plans reflects this

Box 15.1: GCW experiences in establishing HACCP plans and their implementation

Assemble team: The candidates were identified rapidly and their commitment secured. Most of those selected were keen to be involved but concerned about the likely time input. In the approach adopted by Gold Coast Water (GCW) the majority of work is done by the time leader, with the other team members adding advise and experience.

Describe water supply: It is estimated that a water plant needs a day or two, plus a few hours to create the flow chart. In a reticulation system, more time may be required but the GCW experience suggests that it is not practical to construct a detailed reticulation flow diagram and it can be kept at a relatively simple level (reservoir ▸ pipeline ▸ secondary reservoir ▸ rechlorination ▸ customer).

Conduct hazard analysis: This depends upon the approach taken, use of the probability/consequence matrix or a brainstorming approach. GCW favour a brainstorming approach, which includes identification not only of potential hazards but also control issues. It is estimated that this takes about a day for each plant. This is where choosing the right team can pay dividends with an appropriate balance being stuck between theory/science and practical experience. It may be that this step will be revisited as the monitoring and corrective actions are established.

Identify control measures, monitoring and corrective actions: This was the stage at which procedures were written. The approach taken by GCW was to adopt a similar format for all procedures, including:

introduction (including the theory behind the process step);
monitoring and control measures;
corrective actions;
reporting process; verification information.

The team leader wrote each procedure and the time taken for each varied (between and day and a week). In order to write each procedure, however, it was important to gain detailed knowledge of the process and this meant spending time with operational staff, attending repair activities, reservoir inspection and so on. For a water plant it has been estimated that ten weeks were required to cover the whole of the facility, while the reticulation system was more complex and spread out and took approximately four months. During the setting of critical limits, some analytical work was done to validate the limits and time was spent having measuring instrument and calibration procedures verified. In some cases it was necessary to purchase additional instrumentation. A possibly unforeseen time commitment may include staff negotiation to ensure that any procedures requiring a change in work practices are accepted.

Box 15.1: GCW experiences in establishing HACCP plans and their implementation - continued

Incident response: A highly evolved Incident Management Procedure (QP-19) was already in place. However, it is estimated that this may take between one and two weeks to develop, as agreement is required from both management and operational staff.

Supporting programmes: ISO 9000 meant that training and asset management was already in place, so there was not a significant time commitment for this step.
Recording keeping: This was not a significant time requirement as GCW already had a record keeping system established under ISO 9000.

Validation, verification and audit: Critical limits were validated at the procedure writing stage. Under ISO 9000, GCW already have a good internal audit system and mandatory review of the quality system by senior management. The HACCP procedures written for the plan include specific verification tools for the various processes. GCW have an estimated 40 HACCP-type procedures in their system and it is thought that it would take one person two to three weeks full time to audit these on site and write the reports.

Certification: In the case of GCW this took three days of scrutiny from the certifying body and can be a positive experience, with the referees adding their experience and insight to the process.

15.2 COST IMPLICATIONS

Cost is an important factor in the implementation of any new approach or procedure. There seems to be a fear that risk-based approaches to water safety management, such as the water safety plan, will increase costs of water production and distribution. There is, however, no solid reason why this should be so and it would be expected that some cost aspects would reduce.

It would be expected that microbial testing would significantly decrease but process monitoring would increase as a result of adopting a water safety plan. This may offer opportunities for significant savings in countries where consumables for microbial testing are expensive. A utility in a developing country, for example, calculated that switching to a water safety plan approach would reduce their routine monitoring bill by almost one-third. Even in developed countries, the recurrent costs of using process indicators (such as turbidity, chlorine, residuals, pH, etc.) for monitoring will almost certainly be lower than those for monitoring *E. coli* as a routine operational tool. The use of process indicators for monitoring and the restriction of microbial analysis to less frequent verification provides greater assurance that water safety is being achieved. In many cases, the equipment for on-line process monitoring will exist (particularly in larger supplies). Even where this requires initial capital investment the recurrent costs would be expected to be lower than routine microbial testing costs. Where there are current requirements for regular monitoring of, for example, *Cryptosporidium* (as in the UK), costs would certainly be reduced by using a risk-based approach. In this instance the analysis of *Cryptosporidium* could be restricted to periodic risk assessments and validation exercises, with cheaper surrogates used for monitoring (e.g. turbidity) and verification (e.g. *Clostridium perfringens*).

The following boxes present a series of examples drawn from water suppliers in Australia, Europe and Uganda, with experience in using a risk-based approach, similar to the water safety plan, such as those with HACCP plans and/or ISO accreditation. They are qualitative in style, as cost-implications tend to be location specific, but aim to give an insight into likely cost implications, such as what costs may be entailed and where these are likely to be accrued (e.g., staff costs, equipment). All costs have been standardised as Euros.

Box 15.2 Gold Coast Water, Australia

One retail water supplier developed a HACCP plan for their water supply using their existing ISO 9001 and 14001 accreditation as a starting platform. In this case, the development of the HACCP plan cost approximately €11,500 in consultant support and roughly two months of a water quality engineer's time. Ongoing audit costs are estimated at €1,700. This utility considered the development of a HACCP plan to have greatly improved their water safety management and provided a much more transparent means of demonstrating good practice and due diligence.

Box 15.3: Melbourne Water, Australia

A bulk supplier whose total number of consumers is 3.5 million people developed a HACCP plan to cover all their operations, including their retail suppliers. This supplier indicated that establishing the HACCP plan involved 12 months of one existing staff member, which was estimated at €34,500 with an additional €17,200 spent on a consultant to perform a risk assessment of their whole supply (which is very large). This utility did not consider that they accumulated any additional costs for monitoring, but do require 6-monthly audits which cost in the region of €2,800. Every 3 years have an updated risk assessment performed, which costs €5,600. This utility also has a team of internal auditors, all of whom have other jobs, who undertake about 6 audits per year. This supplier considers the HACCP plan to be essential to their water safety management and a significant improvement over the use of microbial tasting as an operational tool. They have been able to re-orientate their microbial testing to verification and have been able to provide more effective internal management and audit of performance.

Box 15.4: Retail water supplier, Australia

In a second retail water supplier that supplies a smaller city, a total of 8 HACCP plans have been developed including for a very small package plant, two medium size treatment works, a distribution system with 70 reservoirs and four wastewater plants. The utility estimated that HACCP plan creation costs would need to cover 2-3 months of staff time to understand the process and document the procedures and plan. It was noted that this may be extended if significant staff and community consultation were required. The view of the utility was that where such plans had taken longer to complete, this reflected that staff had not been seconded to developing the HACCP plan full-time.

The experience of this utility was that implementing the HACCP plan did not result in extra staff costs at the treatment plants. It simply made staff re-orientate how they worked to become more focused on ensuring that critical risks were controlled and spent less on issues of limited importance. It was also noted that staff were generally more content as they felt they were more involved in determining how safe water can be assured. This utility did recruit an additional staff member for monitoring the distribution system, as they previously did not have a member of staff responsible for investigating consumer complaints or evaluating monitoring data. It could therefore be argued that this was not an additional cost accrued through a switch to HACCP, but was a post that was required irrespective of the approach to safety management adopted. It was noted that where water quality staff exist, no additional staff costs would be expected given that implementing HACCP would simply result in a re-orientation of work plans rather than creation of a new job.

Costs were accrued for equipment purchase, in particular on-line turbidity meters, pH and chlorine meters and telemetry for unmanned sites. Overall, the utility found an annual increase in distribution monitoring of €63,000 but noted that a neighbouring water supplier with a much larger system did not seem to accrue any additional costs when implementing their HACCP plan.

This utility listed a large number of benefits of the HACCP system. There was a clear feeling that water safety was now much more effectively controlled, as risk assessments were carried out on all processes and because control points and critical limits were established. They noted that it was easier to monitor staff and that incentives were created for staff to improve their performance. The HACCP plan was seen as having a particular value as all senior staff were informed by automatic email if a critical limit was exceeded, thus promoting more timely responses. Asset management was seen as being significantly improved, as the HACCP plan focuses on critical risks and therefore resources could be used more effectively. It was also noted that continuous improvement and reassessment of risks were automatic by-products from the HACCP plan. The final statement of this utility was that HACCP was well accepted by their staff who 'would not consider going back to the old system'.

Box 15.5: European water utility

Data was obtained from a European water utility regarding the cost of implementing a ISO 9000 series accredited management system. It should be noted that this company has to operate a water quality control programme based on microbial testing at the same time because of regulatory requirements. The company serves nearly 7 million people, has an operational area of 14,000 km^2, and operates 150 treatment works with an average production of 2000ML per day, with 380 service reservoirs/water towers and 40,000 km of pipe. The cost of staff time to run the ISO management system, primarily accrued through documenting the process, is estimated to be €141,000, with audit costs in the region of €21,000 to €28,000. This utility notes that they are unable to benefit from expected reductions in cost of microbial monitoring because of current regulations, but did not believe that risk based approaches would increase monitoring costs and may actually lead to a reduction in costs.

Box 15.6: Ugandan experience

In Uganda, as in many other countries, determining the overall costs of producing water safety plans must take into consideration a number of factors. In the first instance, significant external consultant support was provided in order to work with teams from the water supplier to provide training in water safety plan preparation and the relevant tools. This involved approximately nine weeks of UK consultant time (with an associated cost of approximately €35,000) and local consultant time (costing a further €7,000). Equipment and consumable purchases added a further €5,600. Direct local costs for the supplier were more limited and came to approximately a €2,100. Staff time was considerable, but was generally incorporated into normal working practice and thus was not an additional cost. In total for the Kampala system, the overall cost was in the region of €49,000. However, the majority of these costs related to UK consultant time and were, essentially, capacity building and, as such, should be spread across all subsequent water safety plans developed. In Jinja, for example, the UK consultant coasts were in the region of €12,600 (with local consultant costs of €4,200), while the risk assessment of the supplies resulted in a further €9,800 expenditure. If it is assumed that the National Water and Sewerage Corporation will undertake water safety plans for all 11 towns that they supply, the overall consultant costs for each supply would be in the region of €6,300.

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Appendix A

Extracts from the Gold Coast Water (GCW) Water Quality Management System

In addition to the cases studies that have run alongside individual chapters, this appendix contains extracts from the Water Quality Management System HACCP (Hazard Analysis Critical Control Point) plan of Gold Coast Water (GCW), adapted slightly to reflect the water safety plan terminology. GCW operates several thousand kilometres of water mains with 74 storage tanks and two water treatment plants (Molendinar and Mudgeeraba) in Australia.

A1 INTRODUCTION

The HACCP plan (Hazard Analysis Critical Control Point) from which this example water safety plan extract has been derived is scoped to cover the entire water system from catchment to tap and is a dynamic document continually evolving as increased knowledge and experience present opportunities for improvement. There is very little detail on monitoring, corrective action, reporting, records and verification within the body of the plan, as such information is contained in written procedures, which are referenced in the plan. In the day-to-day activities of operational staff, the plan document has little relevance. The operational procedures that implement the plan, however, are well-known. Staff understand that product quality failures are detected and reported in this system. They also realise that adherence to procedures is a defence whereas ignorance of procedure places individuals in a compromised situation. Almost all procedures received staff approval before being signed by management.

Management themselves are constantly presented with the opportunity to interpret trends in operational failure reports and instigate planning or strategic responses if necessary.

A2 TEAM

To construct the initial system GCW gave the initiative formal project status and allocated funding accordingly. Because of the size of the system, it was appropriate to have a dedicated water quality officer to administer the project. A team was assembled to obtain the necessary detailed information about the water supply chain.

Team expertise includes:

Quality systems – chemistry and biology;
Water treatment – process design and control;
Senior water treatment plant operator;
Microbiologist – with extensive water experience;
Co-ordinator of catchment management;
Water storage and distribution management;
Electronic control systems;
Senior Ranger (Hinze dam); and
Customer liaison.

A3 WATER SUPPLY DESCRIPTION AND HAZARD ANALYSIS

GCW strives to produce potable water that reaches its customers complying with those parameters of the Australian Drinking Water Guidelines relevant to the nature of its harvesting, treatment and distribution operations.

The distribution for Gold Coast has been divided into discrete reservoir zones. The zones are delineated by pressure differences or other supply considerations. Each zone has a number of test points that are either reservoirs or sites unambiguously linked to reservoirs.

The team leader, in conjunction with the various team members, identified all the process steps involved in the harvesting, treatment and distribution activities. From this identification, process flow diagrams were created (See A8 for examples of flow charts of the Molendinar water purification plant and the reticulation system) and then returned to appropriate staff for on-site verification. The next stage was to conduct the hazard analysis. This was done by holding workshops and carrying out numerous on-site discussions with facilitators and as many operational staff as practicable. It was valuable to engage a variety of operational staff as important additional 'fragments' of knowledge were obtained in this way.

A4 MONITORING, CONTROL AND CORRECTIVE ACTION

Control measures were identified. For most control measures the matter of corrective action was dealt with by incorporating into monitoring and control procedures. For other issues it was more suitable to state the corrective action in the plan. Development of monitoring, critical limits and corrective actions was achieved through a series of workshops, meetings, impromptu discussions (usually on-site), literature searches and experimentation.

A5 INCIDENT RESPONSE

GCW uses an Incident Management Plan that describes how incidents and emergency situations will be managed. This plan refers to the Incident Management Procedure. The advantage of the Incident Management Procedure is that it is activated by certain critical limits (among other things) and that corrective action is then specifically tailored to the conditions of the particular incident. For example when cyanobacteria levels in the storage exceed a critical limit, declaration of an incident is mandatory.

A6 VERIFICATION AND INTERNAL AUDIT

The water quality management system has been designed to avoid reliance of 'end product testing' as system verification. This has certainly been the case with respect to the water plants. End product testing, however, is required by the guidelines and still has an important role to play in the verification of distribution system activities. The plan treats each of the activities and process steps as ‘barriers’ to product degradation and each barrier has a role to play, standards expected of it and specific mechanisms to achieve these standards. System verification has been built into key procedures by creating an auditable accountability trial that encourages continuous improvement.

GCW has structured its internal audit system to have maximum effectiveness by using trained internal auditors having no direct involvement with auditees and by rotating auditor tasks. Appropriately qualified persons carry out audits requiring technical understanding. Further, many key operational procedures are written so as to prompt the internal auditors to matters requiring close attention.

A7 SUPPORTING PROGRAMMES

Many hazards may be related to the condition and suitability of equipment, the management of assets and the competency of staff. These are dealt with through supporting programmes. These include:

Service Level Agreements;
Process Audits;
Asset Management; and
Staff Training

A8 FLOW DIAGRAMS

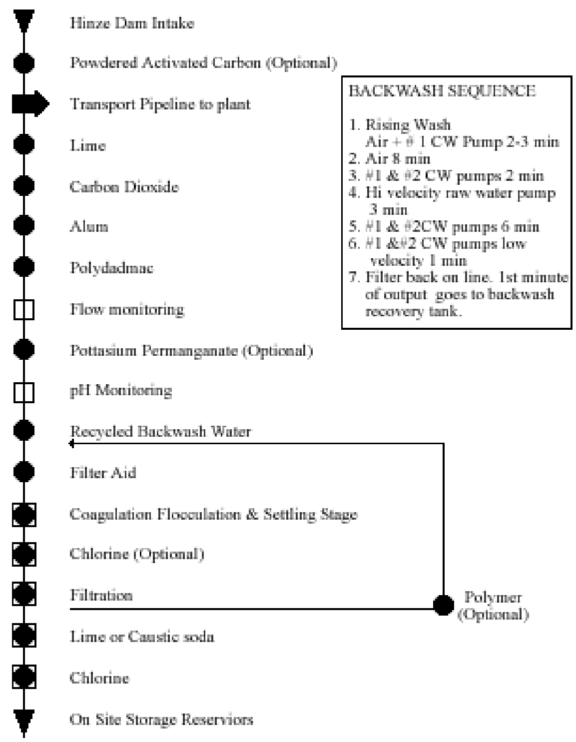

Figure A1: Molendinar water purification plant – HACCP process diagram

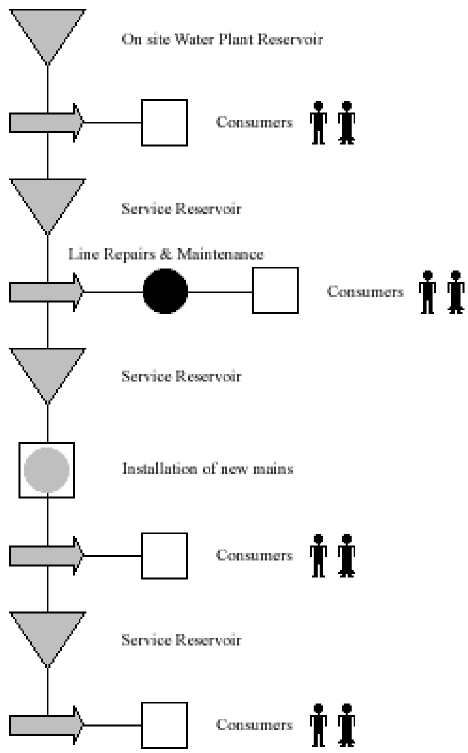

Figure A2: Reticulation system – HACCP process flow diagram

A9 EXTRACTS FROM THE WATER QUALITY MANAGEMENT PLAN

Table A1: Catchments and dams

Activity or process step	Potential hazards	Control issues	Critical limits	Monitoring and/or control measures	Corrective actions
Water Harvesting & Storage					
Agriculture activities	Faecal contamination of waterways	Grazing activities	Site specific limits for colour, turbidity, bacteria, pH, salinity and nutrients, to be advised	Regular stream Monitoring by Community Services directorate of 13 catchment sites. Program to be revised and procedure for critical limits and corrective action to be created. Refer also to existing Catchment Management Plan to control current activity. Town plan prohibits further such development in catchment.	Detection of significant pollutant levels initiates investigation by GCW staff. Community awareness and support fostered. Landcare groups consulted. Complaints can be made to relevant Government agencies (eg EPA) Government agencies can be approached to alter or introduce regulation.
	Algal blooms from nutrient run off	Dairying activities	Refer procedure	Refer to the Algal Management procedure for detail.	See Algal Management Procedure.
	Pesticide & herbicide run off	Crop growing			
	Erosion	Land management			
Urban and industrial activity	Seepage from un sewered properties	Monitoring of un sewered domestic and commercial sites.		PE&T directorate to monitor sewage discharges and regular stream monitoring is carried out.	Improvement notices to be issued to owners found discharging substandard effluent.

Activity or process step	Potential hazards	Control issues	Critical limits	Monitoring and/or control measures	Corrective actions
	Chemical and microbial pollution from stormwater, poor industrial practices and spillages	Stormwater control. Industrial practices eg. usage, storage and transport of fuels and chemicals		No control over run off or spillage from existing activities. Regular scientific tests are carried out on catchment waters. Town plan requires run off control for future approvals.	Detection of significant pollutant levels initiates investigation by GCW staff. Overt pollution events with clear evidence can be reported to EPA and fines issued by delegated council officers.
	Physical pollution from erosion and rubbish dumping	Development activities eg. Building, roadworks clearing, tourism expansion etc.		Rangers inspect catchment areas and maintain good awareness of local activity. (Rangers reside in the catchment).	Illegally dumped rubbish is removed.
Recreational activities	Nutrient release, erosion and ecological damage	Control of fishing, camping, picnics, social & sporting events, horse riding etc.		Catchment Recreational Management Plan and Procedure OM-06-03 (Recreation Management). Regular scientific tests are carried out on catchment waters. Refer procedure OM-06-08 Fish release into Hinze & Little Nerang Dams and OM-06-03 Dam Recreation.	Regular Range patrols (power to issue. Fines under Local Law 13) Detection of significant pollutant levels initiates investigation by GCW staff. Loads containing foreign or diseased species are rejected.
	Rubbish dumping	Availability of receptacles Monitoring of tracks		Refer Hinze & Little Nerang Dams Recreational Management Policy. Rangers carry out daily patrols of tourist locales.	Illegally dumped rubbish is removed. Many existing tracks have been closed by rangers.

Activity or process step	Potential hazards	Control issues	Critical limits	Monitoring and/or control measures	Corrective actions
	Sabotage	Security		Regular Ranger patrols are carried out and an after hours security firm employed. Completed security coverage is not feasible.	QP-19 (Incident Management Plan) details organisational response to unpredicted events.
Natural Events	Dam turnover	Monitoring of temperature stratum		Both dams are monitored weekly at multiple depths for Fe Mn nutrients, turbidity and colour.	Manipulation strategies such as oxygenation are being investigated.
	Erosion	Land use practices Bank inspections Drainage control		Feeder streams are regularly monitored. Rangers have extensive erosion control within GCW area.	For serious erosion events outside GCW control consult EPA, Landcare groups or State Rangers.
	Disturbance of the natural ecological balance in catchment from all activities	Ecological monitoring.		Insufficient ecological baseline data at present. No current biodiversity monitoring undertaken.	Plans are being developed to increase this field of monitoring and develop both interpretive procedures and corrective action.
	Damage from feral animals			Rangers use various removal techniques.	
	Fire	Risk reduction & control		Refer to the Hinze Dam and Little Nerang dam Bushfire Management Plan	Refer emergency response section of plan
Dam walls	Threat to supply from wall failure	Monitoring of wall condition	Maintain pressure monitoring	Refer procedure OM-06-06 Dam Surveillance Multiple pressure monitors in dam walls.	Manager Infrastructure Services to arrange stabilisation. Refer procedure OM-06-103 "Dam Structural Failure". Refer GCCC Counter Disaster Plan.
Water transport intake towers	Interruption to supply optimisation of "draw-off" level	Structural integrity of installation		Regular inspection by Rangers.	Refer procedure OM-06-107

Activity or process step	Potential hazards	Control issues	Critical limits	Monitoring and/or control measures	Corrective actions
		Efficiency & reliability of equipment Power supply		Telementry maintenance schedule carried out by Operations & Maintenance. Valves can be operated manually at intakes.	Parts criticality analysis to be developed. Mudgeeraba can switch to LND supply.
		Telemetry		Maintenance schedule carried out by O & M.	
		Staff knowledge & competence		Refer procedure OM-01-200 "Optimising Raw Water"	Refer procedures OM-01-200.
Break in head tanks	Interruption to supply	Structural integrity of installation		Regular inspections by Rangers.	Mngr. Infrastructure Serv. To arrange stabilisation.
		Telemetry Control System		Maintenance schedule carried out by O & M.	Parts criticality analysis to be developed
		Mechanical & electrical maintenance		Maintenance schedule carried out by O&M	Parts criticality analysis to be developed
		Vandalism		Regular inspections by Rangers.	Fencing required
Raw water pump station	Interruption to supply	Staff knowledge & competence	Adhere to procedure OM-06-04.	Refer procedure OM-06-04 (Dam Pump Station Operation)	Refer procedure OM-06-04 (Dam Pump Station Operation)
		Telemetry		Maintenance schedule carried out by O & M	Equipment can be controlled manually
Raw water pipelines	Interruption to supply Bacterial contamination from biofilm growth	Efficiency & reliability of equipment		Maintenance scheduled carried out by O & M	Parts criticality analysis to be developed.

Activity or process step	Potential hazards	Control issues	Critical limits	Monitoring and/or control measures	Corrective actions
		Maintenance & repair of pipelines from Hinze & LND to water plants	Regularly inspect & maintain lines.	Maintenance schedule carried out by O & M as per S.L.A. schedule.	No alternative pipeline, repairs must be carried out immediately.
	Compromising the health of Consumers connected to the raw water pipelines	Control and protection of the consumers using the raw water pipelines		Signage posted and separate plumbing systems in place. Users advised water not potable. List of connections located in QEMS.	Refer Procedure OM-20 (Water Algal Management Plan)
Dam capacity	Poor water quality during low level periods	Water plant treatment capabilities		Plants to be certified to HACCP standard.	Refer Molendinar & Mudgeeraba HACCP plans.
	Supply inadequate to meet needs	Dam capacity		Dam capacity under question. Ability to withstand drought requires attention Planning is reviewed periodically.	Allowance has been made for increasing capacity. Brisbane water can be accessed to supplement supply.

Table A2: Molendinar Water Plant

Activity or process step	Potential hazards	Control issues	Critical or operational limits*	Monitoring and/or control measures	Corrective actions
Raw water optimisation	Increased probability of microbial contamination and process damage by drawing from low quality stratum.	Optimising draw off level Presence of chlorine resistant pathogens.	NA	Refer Procedure OM-01-200 "Raw Water Optimisation"(includes triggers for C&G testing) Weekly profiles and bacterial test are performed. Refer Catchment Management Plan for identification and control of potential protozoan sources.	Refer Procedure OM-01-200 "Raw Water Optimisation"
Carbon dosing	Offensive and toxic organics passing through to treated water.	Suitability of carbon type		Carbon currently in use is recommended by CRC tests.	Process Audit/Research section monitor new products and industry trends.
		Availability and quality of carbon supply		Supplier certified to ISO9002 and adequate supplies held.	Alternative carbon suppliers are available.
		Efficiency and reliability of process & equipment.		Service agreement exists with O & M. Maintenance schedule for facility exists. Unit and process are functional but require frequent monitoring.	Refer SLA document between O & M and Service Delivery
		Dosage determination & control	Dosing limits are event determined.	Refer Procedures OM-01-201&2 "Carbon Dosing Protocol & Procedure"	Refer procedures OM-01-2001 and 01-202

Activity or process step	Potential hazards	Control issues	Critical or operational limits*	Monitoring and/or control measures	Corrective actions
		Staff knowledge & competence		Senior operator trains day labour and verifies dosing.	Retrain operators.
		After hours control.		Failure alarms on key components linked to telemetry system. Duty operator to respond.	Backup response by 24hr. Call centre.
Recycling of backwash water	Reintroduction of concentrated chemical & microbial contaminants. Effect on chemical dosing strategy.	Control of manganese levels.	0.5mg/L soluble Mn (operations limit)	Refer Procedure OM-01-208 "Monitoring of Recycled Backwash Water". Backwash water is 1° settled with solids to sewer.	Refer procedure OM-01-208 Monitoring of Recycled Backwash Water.
		Control of microbial hazards	50,000 cells/ml of "blue green algae". Faecal coliforms < 100 cfu per 100 ml	Refer Procedure OM-01-208 "Monitoring of Recycled Backwash Water"	Refer procedure OM-01-208 Monitoring of Recycled Backwash Water.
		Staff knowledge & competence		Refer competency testing regime (Molendinar)	Retrain operators.
CO_2 dosing	Detention in concrete lined mains causes increases in pH, which reduces efficacy of chlorine residual and promotes precipitation events.	Availability and quality of CO_2 supply. Availability & quality of CO_2 supply		Supplier certified to ISO 9000 series.	Alternative supply uncertain but plant can function without CO_2 at the expense of boosting alkalinity.
		Efficacy and reliability of dosing unit	Alkalinity of 35-50 mg/L	Maintenance & Operation of unit are the responsibility of BOC gases.	Refer Procedure OM-01-204 (Carbon Dioxide Dosing)

Activity or process step	Potential hazards	Control issues	Critical or operational limits*	Monitoring and/or control measures	Corrective actions
		Dosage determination & control	Outside range for > 48 hours = report	Refer Procedure OM-01-204	Refer Procedure OM-01-204
		Staff knowledge & competence		Refer competency testing regime (Molendinar)	Retrain operators.
Coagulation flocculation & settling	Unacceptable levels of physical chemical and microbial impurities and/or toxins in treated water.	Maintenance of mechanical and electrical system.	Inspect daily.	Refer Procedure OM-01-210 "Daily Plant Inspection ". No scheduled maintenance.	Contact O & M for reactive repairs. Spare butterfly valve can be obtained.
Inlet flow control		Maintaining a correct and known flow into the plant.	Calibrate monthly.	Refer to O & M Instrument Maintenance Schedule for Molendinar W.P.P.	Refer SLA document between O & M and Service Delivery
		Staff knowledge & competence		Refer competency assessment regime (Molendinar)	Retrain operators
Offline clarifier control	Concentrations of bacteria and algae in redundant clarifiers may become problematic when plant is in contact filtration mode for long periods	Control of Microbial growth. Changing from direct filtration		Refer to Procedure OM-01-216 "Clarifier Changeover Procedure"	Refer to Procedure OM-01-216 "Clarifier Changeover Procedure"

Activity or process step	Potential hazards	Control issues	Critical or operational limits*	Monitoring and/or control measures	Corrective actions
pH control of dosed water	Poor coagulation and flocculation could lead to pathogens breaching the filter barrier. Aesthetic colour problems could occur..	Controlling pH in the flocculation process.	6.5 to 7 (normal) 7-7.3 (Mn04 dosing ranges in brackets) 5.7-6.4 (6.9) for 4-8 hrs=report 5.7-6.4(6.9>8hrs=shutdown/report 7-7.5 for 4-8 hrs= report 7-7.5 for > 8hrs=shutdown/report <5.7 for 2hrs =shutdown/report >7.5 for 2 hours= shutdown /report	Refer Procedure OM-01-209 "Molendinar Dosed Water pH	Refer Procedure OM-01-209 "Molendinar Dosed Water pH"
		After hours pH control		pH probe has high & low alarms with variable time responses.	Auto dialler calls programmed numbers until human response achieved.
Pre Lime	If pre lime fails, CO_2 dosing is reduced and alkalinity falls.	Lime (Ca0)			

Activity or process step	Potential hazards	Control issues	Critical or operational limits*	Monitoring and/or control measures	Corrective actions
	Pre lime is required if alum dosing is sufficient to force raw water pH too low.	Availability & quality of lime supply.		Supplier certified to ISO 9000 series.	Alternative suppliers available.
		Efficacy and reliability of dosing unit.		Refer to O & M maintenance schedule redundancy available on dosing equipment.	Refer SLA document between O & M and Service Delivery.
		Dosage determination & control.	Event determined	Refer Procedure OM-01-203 "Pre Lime Dosing"	Refer Procedure OM-01-203 "Pre Lime Dosing"
		Staff knowledge & competence.		Refer competency testing regime (Molendinar)	Retrain operators.
		After hours control		Key components are alarmed to dialling system.	Refer Procedure OM-01-203 "Pre Lime Dosing" and OM-01-209 (ph Control at Molendinar.
Alum dosing	Refer dosed water pH hazards.	Alum			
		Availability & quality of alum supply.		Supplier certified to ISO 9000 series.	Alternative supplier available.
		Efficacy and reliability of dosing unit.		Maintenance schedule, component redundancy.	Procedure OM-01-205 (Alum Dosing @ Mol.)
				Accessibility to spares and tech. Advice Procedure OM-01-205 (Alum Dosing @ Mol.)	24 hour service available.

Activity or process step	Potential hazards	Control issues	Critical or operational limits*	Monitoring and/or control measures	Corrective actions
		Dosage determination & control	True Colour <5.0 CPU >5 for >24 hours = report >10 for >4 hrs = shutdown/report	Procedure OM-01-205 (Alum Dosing @ Mol.) and OM-01-209 "Molendinar Dosed Water pH"	"Molendinar Dosed Water pH" Procedure OM-01-205 (Alum Dosing @ Mol.) and OM-01-209
Polydadmac Dosing	At high flows dadmac control is important for optimal particle removal (turbidity)	Polydadmac (Cationic Polymer)			
		Availability & quality of supply		QA supplier (alternate supplier avail.)	Alternative supplier available.
		Efficacy and reliability of dosing unit.		Maintenance schedule, component redundancy.	24 hour service available.
		Dosage determination & control.	Event determined	Accessibility to spares & tech. Advice. Refer procedure OM-01-206.	Refer procedure OM-01-206 (Dosing of Polymer)
		Staff knowledge & competence		Refer Procedure OM-01-206 (Molendinar)	Retrain operators.

Activity or process step	Potential hazards	Control issues	Critical or operational limits*	Monitoring and/or control measures	Corrective actions
Permanganate Dosing	First line response to high manganese in raw water. Failure places pressure on second mechanism. Dirty water complaints increase if Mn control fails.	Potassium permanganate (optional)			
		Availability & Quality of Supply.		QA supplier (alternate supplier avail.)	Alternative supplier available.
		Efficacy and reliability of Dosing Unit	Treated water soluble Mn levels of <0.02 mg/l	Maintenance schedule, component redundancy. Accessibility to spares and tech advice. Refer also Procedure OM-01-207 (Permanganate Dosing).	24 Hour service available.
		Dosing protocol, determination & control		Procedure OM-01-207 (Permanganate Dosing) Pre filter chlorination downstream removes criticality of this process step.	Procedure OM-01-207 (Permanganate Dsosing)
		Staff knowledge & competence.		Refer competency testing regime (Molendinar)	Retraing operators.
Filter Aid	Small amounts used to achieve high performance in peak demand situations.	Filter aid			
		Availability & Quality of Supply		ISO 9000 certified supplier.	Alternative supplier available.

Activity or process step	Potential hazards	Control issues	Critical or operational limits*	Monitoring and/or control measures	Corrective actions
		Efficiency and reliability of Dosing Unit.		Temporary dosing unit in place due to main unit failure.	Service contract with Jetflo.
		Dosage determination & control.	Event determined	Procedure OM-01-212 (Use of Filter Aid)	Procedure OM-01-212 (use of filter Aid)
		Staff knowledge & competence.		Refer competency testing regime (Molendinar)	Refrain operators.
Solids Control		Solids Control			
	Excessive solids build up increases carryover and effects filter performance.	Effectiveness, reliability & structural integrity of raking system.		Clarifier rake systems are regularly maintained. Refer procedure OM-01-17.	Refer SLA document between Operations & Maintenance Branch Business Units
		Sludge blanket control.		Clarifiers are operated to run with no sludge blanket. Solids go to sewer. Clarifiers not used when plant in Contact Filtration mode.	Refer Procedure OM-01-17 “Clarifier Isolation and Draindown”.
Pre Filter Chlorination	High soluble Manganese in treated water causes dirty water complaints. Taste & odour (overdosing). Disinfection by Products.	Availabilty & Quality of CL2 Supply		QA supplier (alternate supplier avail.)	Alternative sources available.

Activity or process step	Potential hazards	Control issues	Critical or operational limits*	Monitoring and/or control measures	Corrective actions
		Efficacy and reliability of Dosing Unit.		Maintenance schedule, component, redundancy accessibility to spares & tech. Advice.	24 hour Maintenance cover available. (refer S.L.A. with O & M.)
		Dosage determination & control.	Treated water soluble Mn levels of <0.02 mg/l. Report any AAS result >0.02 mg/L	Procedure OM-01-211 (Pre Filter Chlorination)	Procedure OM-01-211 (Pre-Filter Chlorination)
		Staff knowledge & competence.		Refer competency testing regime (Molendinar)	Refer T.S Training Plan.
		Simultaneous high algal counts and raw water manganese.		Procedure OM-01-211 (Pre Filter Chlorination)	Adjust dosing regime and dosing points. Avoid direct filtration.
Filtration	Release of a variety of physical, chemical and microbial impurities into treated water.	Choice and depth of media.		Choice and depth of media determined from extensive pilot plant work.	Resume pilot plant studies. Replace media if necessary. Maintain air and backwash systems.

Activity or process step	Potential hazards	Control issues	Critical or operational limits*	Monitoring and/or control measures	Corrective actions
		Flow control. Performance management/ analysis. Backwashing procedure. Turbidity Control.	Filtered water turb. Of <0.2 NTU >0.2 for 2 hrs = report >0.2 for 5 hrs = shutdown >0.3 for 2 hrs = shutdown single filter>0.3 for 2hrs = take off line Acid sol. Al <0.15 mg/L: Report all failures.	Refer OM-01-213 Filtration & Turbidity Control at Molendinar*	Refer OM-01-213 "Filtration & Turb. Control"
		After hours turbidity control. Mechanical and electrical maintenance of backwashing system.		All filters have turbidity meters which are alarmed as is composite turbidity meter. Refer SLA with Operations & Maintenance Pump redundancies exist.	Upper limit alarm will activate auto dialer call out sequence. Refer SLA with Operations & Maintenance.

Activity or process step	Potential hazards	Control issues	Critical or operational limits*	Monitoring and/or control measures	Corrective actions
		Accidental or deliberate contamination of filters.		No toxic materials are stored near the clarifiers of filter chambers. Facility is locked after hours with CCTV on the electronic gate entry. Standard perimeter barb wire fence in place. Malicious intent action is not controllable as plant is mostly unmanned without movement sensors.	Refer Procedure OM-01-107
pH Correction (lime or caustic)	Compromised disinfection. Failure to meet specification for Corrosive /Alkaline water.	Availability & quality of supply.	pH 6.9 – 7.5 pH > 7.5 or <6.9 for 5 hrs = report >8.5 or<6 for 5 hrs = shutdown & report	QA supplier (alternate supplier avail.)	Alternative sources available. Investigate use of Megapac or caustic.
		Efficacy and reliability of dosing unit.		Unit is effective.	“Contamination of the Clear Water Tank.
		Dosage determination & control.		Refer OM-01-214 Disinfection Control at Molendinar.	Refer OM-01-214 Disinfection Control at Molendinar.
		Staff knowledge & competence.		Refer competency testing regime (Molendinar)	Refer TS Training Plan.

Activity or process step	Potential hazards	Control issues	Critical or operational limits*	Monitoring and/or control measures	Corrective actions
Disinfection (Chlorination)	Failure to eliminate chlorine sensitive pathogens. Taste and odour problems. THM formation.	Availability & quality of Cl_2 supply Efficacy and reliability of dosing unit. (Chlorine delivery unit is not flow sensitive).		QA supplier (alternate supplier avail.) Maintenance schedule, component redundancy, accessibility to spares & tech. advice is available. Weekly bacterial testing is carried out on raw & potable water . Emphasis placed on strict filter turbidity performance (continuous) and chlorine control (continuous)	Alternative sources available. 24 hour maintenance cover available. (refer SLA). Dosing system upgrade budgeted for. Procedure OM-01-214 "Disinfection Control at Molendinar"
		Dosage determination & control.	Cl2 of 1-1.5mg/l with pH 7 to 7.5 Chlorine >1.5 or<1.0>8hrs=report >3 or <0.2 for 1 hr = contact manager for shutdown advice.	Procedure OM-01-214 "Disinfection Control at Molendinar"	Procedure OM-01-214 "Disinfection Control at Molendinar"
		After hours disinfection control.		On line chlorine analyser is alarmed	Back up unit in place. Auto dialler calls until human response.
		Staff knowledge & competence		Refer competency testing regime (Molendinar).	Refer Operations & Maintenance Training Plan.
		DBP monitoring	0.25 mg/l	Regular system monitoring by Scientific Services. Water is naturally low in DOC.	Alternative disinfectants eg. Chloramination
Computerised Control System	Product degradation due to loss of computer control.	Access to expert advice and service.	N.A.	System advice available on call from M.P.A.	System advice available on call from M.P.A..

Activity or process step	Potential hazards	Control issues	Critical or operational limits*	Monitoring and/or control measures	Corrective actions
		Knowledge of and competence in manual plant operation.		Refer procedure OM-01-32 "Changing from Kent to Level 2 Control".	Refer Competency testing regime.
		Power failure.		UPS available for computer system.	Backup diesel generator can supply power to computer system (UPS in place)
		After hours failure.		System has back up hard drive and server.	Change to manual control.

* Procedure included in section A10

Table A3: Storage and reticulation system

Activity or Process Step	Potential Hazards	Control Issues	Critical Operational Limits*	Monitoring and/or Control Measures	Corrective Actions
Reservoir Storage	Physical, chemical & microbial contamination of treated water in reservoirs.	Security of reservoir sites. Structural integrity of reservoirs.	Carry out scheduled inspections.	Refer procedure OM-40-03 Reservoir Monitoring Programme*. All reservoirs are roofed.	Refer procedure OM-40-03 “Reservoir Monitoring Programme”
		Monitoring of internal conditions (physical, chemical & microbial)	True Colour <5c.p.u. Turbidity <1 n.t.u. Total & Faecal Coli’s; 0 c.f.u./100ml Refer also procedure RS-39 “Reservoir Monitoring” for advice re:other parameters	Refer procedure OM-40-03 “Reservoir Monitoring Programme”	Refer Procedure OM-40-03 “Reservoir Monitoring Programme”.
		Reliability of control system	NA	Refer Procedure OM-40-01 “operation of Service Reservoirs”	Refer Procedure OM-40-01 “Operation of Service Reservoirs”. Refer also SLA with Field Services.

Activity or Process Step	Potential Hazards	Control Issues	Critical Operational Limits*	Monitoring and/or Control Measures	Corrective Actions
Management of Transport Pipelines	Ongoing build up of chemo & biofilm. Microbial, chemical & physical contamination from water plant or reservoir failures.	Monitoring and control of organic and inorganic deposits in pipe system.	NA	Refer Procedure SD-17 “Distribution Analysis & Interpretation” Manganese and chlorine included in weekly testing regime of distribution system. Water plants configured for maximum Manganese removal.	Refer Procedure SD-17 “Distribution Analysis & Interpretation” Reactive flushing and swabbing carried out when sloughing occurs. Review distribution sampling results to identify areas requiring routine attention. Ongoing review of industry developments in chemo/biofilm control techniques.
		Monitoring and maintenance of pipe system integrity.	NA	O & M staff provide asset condition feedback on service request forms (OM-08-0001) SD staff map all mains breaks to identify trends and instigate replacement projects. Routine inspection of all trunk mains occurs.	Recommendation for capex made. Recommendation for capex made. Trouble spots placed in works programme.
		Knowledge and control of reservoir distribution areas.	NA	Refer Procedure OM-40-01 “Operation of Service Reservoirs” and procedure RS-04 “Network Manipulation of Trunk Mains”	Refer Procedure OM-40-01 “Operation of Service Reservoirs” and procedure RS-04 “Network Manipulation of Trunk Mains”

Activity or Process Step	Potential Hazards	Control Issues	Critical Operational Limits*	Monitoring and/or Control Measures	Corrective Actions
		Distribution System Monitoring	Plate count <100 cfu/ml. Turbidity < 1 n.t.u True colour <5 c.p.u. Faecal/total coli's 0 c.f.u./100 ml Refer also procedure RS-40.	Refer Procedure SD-17 "Distribution Analysis and Interpretation" and OM-40-03 "Reservoir Monitoring Procedure".	Refer Procedures SD-17 "Distribution Analysis and Interpretation", OM-40-03 "Reservoir Monitoring Procedure" and OM-40-04 "Network Manipulation of Trunk Mains"
	Inability to control pressure and flow to specification.	Monitoring and maintenance of devices to prevent pressure extremes.		Refer to procedures OM-07-22, 23, 27, 28 which deal with testing maintenance and repair of devices.	Refer to procedures OM-07-22, 23, 27, 28
	Physical, chemical & microbial contamination due to repairs, maintenance and development work.	Work Techniques	"Flush till Clear" Instruction applies to all line repair work.	Internal quality audits of Civil Works - Water procedures carried out in situ verify flushing regime is adhered to. Bacto testing has verified procedure is effective.	Refer to the OM-07 range of procedures which cover all maintenance and repair activities carried out by Operations & Maintenance.
		Contractor control	NA	Meter replacement contractors sign a formal agreement detailing flushing instructions. Infrastructure Services branch provide a team of experienced contract inspectors for new mains.	Enforce agreement penalty clauses. Sub-standard work can be rejected at any stage of contract.

Activity or Process Step	Potential Hazards	Control Issues	Critical Operational Limits*	Monitoring and/or Control Measures	Corrective Actions
		Staff knowledge and competence		New Field Staff are placed with experienced personnel for 3-6 months. Any changes in practices or equipment are demonstrated to involve staff & proceduralised.	All staff are subject to periodical performance appraisals. Field quality audits are carried out as part of ISO 9000.
		Response times		Breakage response times are detailed in SLA.	Refer Service Level Agreement with Operations & Maintenance
		New connections	Obtain bacterial & pressure certificates.	New mains must pass bacterial & pressure tests before connection to the live system.	Refer to Standard Specifications & Drawings (Water) 1999 edition
	Leaching of toxic substances from component linings.	Evaluation & approval of components.	Compliance with AS4020 required.	Refer procedure SD-01 "Approval of New Water & Sewage Products"	Refer procedure SD-01 "Approval of New Water & Sewage Products"
	Leaching of toxic substances into polyethylene pipes.	Selecting appropriate sites for installation of Polyethylene. Staff awareness of propensity of solvents to traverse PE.	Compliance with AS3500 required.	Refer procedure SD-01 "Approval of New Water & Sewage Products"	Replace pipe with resistant material or remove hydrocarbon source.
	Physical, chemical & microbial contamination of pipelines due to backflow.	Prevention of backflow from residences into mains.	All meters to have non return fitting.	All new domestic meters comply with AS3565.	

Activity or Process Step	Potential Hazards	Control Issues	Critical Operational Limits*	Monitoring and/or Control Measures	Corrective Actions
		Prevention of backflow from businesses into mains.		Water supply law requires that all properties with risk to water supply will have backflow prevention.	GCW has no control over these devices. Owners are responsible for maintenance.
		Failure of Fire fighting system check valves.		Owners required to comply with AS1851 series re: fire system maintenance.	GCW has no control over these devices. Owners are responsible for maintenance.
	Physical, chemical & microbial contamination of pipelines due to standpipe usage.	Control of standpipe distribution control, management and monitoring of usage practices.	NA	Procedure RS-01 “External Metered Standpipes” . Forms accompanying the procedure describe terms & conditions. Designated fill sites are inspected weekly.	Local laws give Reticulation officers to fine operators falling to adhere to terms and conditions in RS-01.
Cross connection of raw & treated water lines.	Physical, chemical & microbial contamination.	Control of areas where raw & treated water are separated only by valves.	Compliance with FS-09v	Potential cross connections are marked with red valves. Refer procedure OM-07-19 “Control of Red Valves”	Procedure OM-40-108 Contamination of Water Reticulation System.

Activity or Process Step	Potential Hazards	Control Issues	Critical Operational Limits*	Monitoring and/or Control Measures	Corrective Actions
Continuity of Supply	Failure to supply.	Control of Reservoir levels. Breakage response times Reservoir storage capacity and trunk delivery limitations Alternative supply methods	NA	Refer Procedure OM-40-01 "Operation of Service res." Prioritising system in place (refer SLA with Operations & Maintenance) Infrastructure Services monitor population trends to anticipate needs. Booster pumps available to overcome trunk inadequacy during extreme demand Refer Proc. OM-40-04 "Network Manipulation of Trunk Mains."	Refer Procedure OM-40-01 Operation of Service Reservoirs. Refer SLA with Operations & Maintenance. Forecasts can be revised through system failure feedback eg. QP-19 Incident Management Plan. Refer Procedure OM-40-04.
Importation of Brisbane Water via Logan Reticulation system.	Failure of Brisbane Water to provide water to specification.	Formal agreement with Brisbane Water (and Logan) specifying quality parameters. Monitoring incoming Brisbane water quality.	NA	Monthly bacteria monitoring of Logan City exit point. Beenleigh Rechlor facility has continuous pH. turb & chlorine readings. Weekly bact monitoring of water leaving rechlor facility.	Refer procedure OM-40-06 "Beenleigh Rechlorination" and Bulk Water Agreement with Brisbane Water & Logan City.

Activity or Process Step	Potential Hazards	Control Issues	Critical Operational Limits*	Monitoring and/or Control Measures	Corrective Actions
Rechlorination of Brisbane Water	Microbial contamination of product. Taste, odour & health problems associated with Chlorine. Taste & odour problems associated with Logan water.	Availability & quality of Cl_2 Supply efficiency and reliability of dosing unit. Dosage determination & control. Staff knowledge & competence. Disinfection by products.	pH 7 to 8 $C1_2$ 0.2 to 1.0 mg/L Turbidity <1 ntu (time limits apply for all failures)	Quality assured supplier. Back up supply not critical. Scheduled maintenance by Operations & Maintenance. Refer Procedure OM-40-06 "Beenleigh Rechlorination Facility" Contact Logan/Bris. Re T&O complaints or failure to meet agreed quality standards. Regular monitoring by Scientific Services.	N.A. Refer SLA between Service Delivery & Operations & Maintenance. Refer Procedure OM-40-06 "Beenleigh Rechlorination Facility" Logan city flow can be shut off by 24 Hour Centre. Adjust dosing or use alternative disinfectant.
Inherited Assets	Deterioration in product quality or service due to poor design and build of infrastructure by GCW. Deterioration in product quality or service due to poor design and build of infrastructure by developers.	Designing to suitable specification. Monitoring of construction activities. Approval of Design plans. Monitoring of construction activities.	NA	Design engineers observe standard specifications. GCW employs contract inspection team. GCW has no control over developers design approval. GCW does not carry out progress inspections on developer contributed assets.	Refer Procedure IS-06 Infrastructure Design" Refer Procedure IS-08 Contract Administration & procedure IS-09 Contributed Assets Audit. Refer Procedure SD-04 "Asset Familiarisation" SD-05 "Recording Substandard Contributed Assets" RS-14 "Asset Handover of Infrastructure"

Activity or Process Step	Potential Hazards	Control Issues	Critical Operational Limits*	Monitoring and/or Control Measures	Corrective Actions
Consumer Feedback	Failure to recognise consumer needs. Failure to recognise system failures at an early stage. Failure to consider customer quality concerns in infrastructure design. Failure to recognise poor field work	Dirty water calls. Taste and odour calls. Illness complaints. Miscellaneous water quality concerns	Operational limits: 8 calls/24 hours 8 calls/24 hours 3 calls/24 hours	Refer procedure RS-08 "Processing Water Quality Enquiries"	

* Procedure included section A10

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Table A4: Validation of critical limits for Molendinar water treatment plant

Critical Control Point	Critical or Operational Limit	Validation	Comments
Carbon Dosing	Event determined.	Dosing is commenced based on a consideration of taste & odour complaints and algal trends. Dosing has to be sufficient to reduce complaints to, 6 per day in accordance with GCW targets.	Powdered activated carbon is added to water to remove unwanted organic compounds. These are usually associated with algal blooms in the supply dam. The amount of required carbon varies with the extent of the bloom and must be determined by experiment. Currently, due to the absence of baseline data, the dose is usually set at the moderate level of 15mg/l then adjusted as circumstances permit.(15mg/l with contact time >2hrs. has been effective in past incidents) Procedures TS-01-202/3 will allow greater precision of future dose determinations.
Recycle of Backwash Water	50,000cells/ml of potentially toxic blue green algae. Faecal coliforms of <100 cfu/100ml	Based on 5% recycle volume and taste threshold of 500 cells/ml blue green algae Faecal coliform limit based on 18 months of data and is designed to prompt investigation when unusual rather than unsafe levels of faecals are detected in the recycle stream.	Recycle can constitute 5% of daily flow. The source of faecals is the bird population that frequents the clarifiers and thickener tanks.
Coagulation, flocculation & settling	Raw water inlet flow		

Critical Control Point	Critical or Operational Limit	Validation	Comments
	Inspect Daily / Calibrate Monthly	Refer Comments	The inlet flow measuring device is important because the output from several dosing pumps is dependant upon its accuracy. Experience has shown that the instrument drifts only minimally over a one month period. However, it is easy for operators to do a visual check of the unit daily for mechanical failure and therefore, because of criticality, it is included in the daily plant check (proc. TS-01-210)
Coagulation, flocculation & settling	Alum Dosing		
	Treated water true colour of < 5 c.p.u.	ADWG (1996) for True Colour	ADWG specify <15 c.p.u. however, 5 C.P.U. has been selected as a Critical limit for corrective action because colour above 5 is noticeable in larger volumes and colour above this value would be indicative of non optimal dosing that would affect other water quality parameters
Coagulation, flocculation & settling	pH Control of Dosed Water		

Critical Control Point	Critical or Operational Limit	Validation	Comments
	6.5 to 7.0 (low manganese conditions). 7.0 to 7.3 (permanganate dosing conditions)	AWWA "Water Quality and Treatment" 4th Edition (chapter 6) See also 'Manganese & Iron Related Problems in Aust Drinking Water Supplies" at (www.clo2.com/reading/ drinking/iron.html)	Although a range of values is shown, set points will be in force at any given time and procedures dictate that significant deviations will be investigated. The range 6.5-7.0 is close to the solubility minimum for Alum. Set points in the range 6.7 or 6.8 are common to minimise the amount of pH correction in disinfection and this is arbitrary. The reaction of permanganate with manganese will yield increased Mn2+ if an acid environment persists. This is undesirable. Refer also procedure TS-01-209 'Molendinar dosed water pH'
Coagulation, flocculation & settling	Carbon Dioxide Dosing		
	Treated water alkalinity of 35 to 50 mg/L as $CaCO_3$	Experimental value	GCW is attempting to overcome the phenomenon of "pH bounce" in concrete lined pipes. This occurrence results in some consumers receiving high pH water. The higher the alkalinity the greater the resistance to pH bounce. The figure of 35 to 50 (suggested by Hunter Water) is a considerable increase over the current figure of about 20. Distribution system pH monitoring of trouble spots indicates this level of alkalinity is probably adequate. Further data is required to optimise dosing.

Critical Control Point	Critical or Operational Limit	Validation	Comments
Coagulation, flocculation & settling	Pre Filter Chlorination		
	Treated Water soluble Mn levels of < 0.02 mg/L	Experimental work carried out for GCW by University of Qld. In 1986 Report entitled "Investigation into Biological Manganese Oxidation and Deposition in the Gold Coast Water Distribution System" by Dr. L. Sly	Report recommended that treated water should have less than 0.01 mg/l soluble Mn. Under normal operating conditions this is achieved. A figure of 0.02mg/L can be tolerated for short periods of time and this figure is chosen for corrective action instigation. Refer procedures TS-01-207 and 211 regarding manganese removal.
Filtration	Filtered Water Turbidity of < 0.2 N.T.U.	Water Industry 'Best Practice'. Refer AWWA publication "Self Assessment Guide for Surface Water Treatment Plant Optimisation" 1997 (chapter 1) by AWWA Research Foundation.	AWWA suggest a filtered water turbidity of < 0.1 should be routine in a modern well run plant. Molendinar plant is capable of <0.1 as a matter of routine and the limit of 0.2 is nominated as a trigger for corrective action. Refer procedure TS-01-213 "Filtration & Turbidity at Molendinar".

Critical Control Point	Critical or Operational Limit	Validation	Comments
Filtration	Acid soluble Aluminium of < 0.15 mg/L	ADWG (1996) for Aluminium	A figure lower than the 0.2 mg/L guideline figure has been chosen in order that corrective Action be commenced before the guideline value is reached.
pH Correction	Treated Water pH of 7.0 to 7.5	Australian Drinking Water Guidelines. See also "Chemistry" by Zumdahl 2nd edition page 625 for equilibrium constant of hypochlorous acid	To maximise germicidal efficiency in potable water, dosed chlorine should be in the form of hypochlorous acid. This species is pH dependant. It is at a maximum concentration below pH5 and is reduced to approx 10% above pH 8.5. In order to avoid corrosivity of water while still providing >50% chlorine as hypochlorous acid, the range of 7 to 7.5 is necessary. A set point within that range will be aimed for. Refer procedure TS-01-214 'Disinfection Control at Molendinar'
Disinfection	Residual chlorine value of 1.0 to 1.5 mg/L (as measured by D.P.D. method) with a pH of 7.0 to 7.5	Australian Drinking Water Guidelines(1996) for Chlorine. A chlorine residual of at 1.5mg/L has proven insufficient to provide all of the Molendinar service area with a >0.1 residual. However, above 1.5 mg/L (leaving the plant) there will be numerous complaints by consumers near the plant.	The chlorine residual will be aimed to a set point within the range 1 to 1.5 mg/L. Outside this range, corrective action will be initiated as per procedure TS-01-214 'Disinfection Control at Molendinar. The procedure also deals with the pH dependence of chlorine residuals. Chlorination levels will be reviewed as the effect of recent buffering capacity increases are assessed.

A10 EXAMPLE PROCEDURES

OM-40-03 Reservoir Quality Inspection Procedure

1 Aim

To provide instruction in carrying out Gold Coast Water's reservoir monitoring programme.

2 Introduction

Water leaving the Molendinar & Mudgeeraba Water Purification Plants is transported to approximately 75 reservoirs around the city. Water is stored in the reservoirs for varying amounts of time depending on demand. Storage reservoirs must be managed, constructed and maintained to preserve product safety and quality at all times. In order to help achieve this goal, the Reservoir Monitoring Procedure has been created.

3 Procedure

3.1 Inspections

Reservoirs will be inspected at least quarterly to determine the safety & integrity of the structure. The following tasks will be performed:

- Any leaks, corrosion and cracking will be noted.
- The roof structure will be inspected to ensure it has the condition to carry out its function. This will include the ability of the roof, hatches and any guttering to resist rain ingress.
- Vents will be examined to ensure they are able to prevent the entry of birds or rodents and allow movement of air over the surface of the water.
- The reservoir site will be assessed to ensure that the reservoir roof does not accumulate excessive leaf litter.
- The reservoir and site should be assessed to determine its ability to resist vandalism. This will include a check of locks on ladders and determining if children or vandals may gain access to the roof by other means such as trees or embankments. Fencing and gates will also be checked. Signs of human activity will be noted.

At least every 5 years every reservoir will undergo physical examination of its internal structure. This will be performed by professional divers (using dedicated potable equipment) and will involve the recording of structural condition, safety, access, type of internal materials, mixing characteristics, sediment sampling and clean out (if required).

The details of inspections will be recorded in such a manner that the current and historical data of each reservoir is available.

3.2 Inspection assessments

Inspection findings will be reported on forms OM40-0301 and 0302.These forms contain prompts and a condition rating system for reservoir components. The reports will be forwarded to the Service Delivery Section. Service Delivery will determine the repair priorities for the various reservoirs based on cost and safety risks. Repairs amounting to less than $1000 can be organised by O&M staff without reference to Service Delivery.

Service Delivery will assess the risks outlined in the inspection reports and if necessary, increase the frequency of inspection. Reservoirs presenting serious risk will be brought to the attention of the Manager Service Delivery who has the authority to approve necessary expenditure.

4 Critical limits and correction action

The CRITICAL LIMIT for reservoir monitoring is that it be carried out quarterly. The corrective action is that Service Delivery section examines the reports and acts to reduce risk to an acceptable level. The reservoir condition reports will be used in the forward planning of asset renewals and upgrades.

In practice, the plan for the testing of the reticulation system provides strong support to the reservoir monitoring procedure. Failures for certain water quality parameters involve a physical inspection of the supply reservoir as part of corrective action. Major reservoirs have intruder alarms connected to the 24 hour control centre.

5 Reporting and verification

If O&M staff fails to carry out programmed inspections, Service Delivery will complete a HACCP excursion form (OM1101) and this will be forwarded to:

Director of Gold Coast Water
Managers of Service Delivery & O&M
Coordinator Civil Maintenance.

Service Delivery will keep records of reservoir reports for at least 5 years. Internal auditors of this procedure MUST select several reservoirs at random and ask to see the inspection reports. They will then determine if the inspection frequency is adequate and if required work has been carried out. Non-compliance with the procedure will be noted in the audit report and a Corrective Action Request raised.

6 References

OM-40-01 Operation of Service Reservoirs
OM-40-02 Reservoir Cleaning
OM-40-108 & 109 Accidental & Deliberate Contamination of the Reticulation System
OM-40-110 Reservoir/Water Tower Major Crack or Failure.
OM-32-113 Telemetry Failure
SD-17 Distribution Analysis & Interpretation.

OM-01-213 Filtration and Turbidity Control at Molendinar Water Treatment Plant

1 Aim

To provide direction on optimal filtration management and turbidity control at the Molendinar Water Plant.

2 Introductory information

It is the role of filtration to remove suspended materials from dosed water to a degree that will permit effective disinfection. To carry out the filtration process, the Molendinar plant has six dual media filters. The top layer of filter media consists of about 0.8 metres of crushed (filter) coal and the bottom layer consists of about 0.15 metres of sand above 0.25m of gravel which is graded in size with the larger particles at the bottom of the filter.

To put the capability of the filtration process into perspective, one must consider that a typical bacterium has a size of about 1micron, which is several thousand times smaller than the average filter sand particle. Clearly, this means that without an effective coagulation and flocculation process, filtration would be seriously limited in its ability to remove pathogens.

Filter performance is commonly measured in terms of turbidity or particle counts. Turbidity is a reasonably sensitive measure of the amount of particulate matter in water and is measured by turbidimeters. Turbidimeters however, cannot tell if the particles in water are gravel fragments, bacteria, algae or cryptosporidia. So, to err on the side of safety, an increase in turbidity is **always** assumed to mean a decrease in the safety of the product. An increase in turbidity of 0.1 to 0.2 can mean a ten-fold increase in particles. Therefore, whenever the turbidity of filtered water increases at a plant it should initiate a process of investigation by operating staff.

3 Monitoring procedure

Under normal conditions, the plant is capable of regularly producing filtered water with a turbidity of less than 0.1 NTU (according to the output from on line turbidity meters). As a matter of diligence therefore any deviation outside of the normal operating values will be treated as suspicious, investigated and rectified. It is not appropriate for operators to wait until critical limits are breached before commencing investigative action.

Each of the six filters at Molendinar is equipped with Great Lakes dual beam turbidimeters. These are sensitive instruments and must be inspected frequently for cleanliness and overall function. Each filter is also equipped with a flow meter and a head loss measuring device. In the first instance, the flow through all six filters is directed according to the output of two pressure sensors located in the clarifiers. The output signal from the six meters (plus a composite meter) is sent to the plant control system and the daily trends can be inspected at any time. Historical information for the past month is also easily accessible. Although the plant is not manned constantly, there is an alarm system designed to call the duty operator and there is back up to a security office if the operator fails to respond to the Critical Limit failure.

Proper management of the filtration process depends on the accuracy and reliability of **ALL** of the above devices and therefore, calibration and maintenance procedures must be carried out as required AND a record of calibrations must be available to the duty operator.

All operators must understand the filter backwash process. Filters will be put into backwash automatically (based on time elapsed, head loss or turbidity) or manually by the operator. The backwash sequence at Molendinar is as follows:

Rising wash (air plus 1 clear water pump for 2-3 minutes)
Air only for 8 minutes
Both clear water pumps for 2 minutes
High velocity raw water for 3 minutes
Both clear water pumps for 6 minutes
Both clear water pumps on reduced velocity for 1 minute
Filter goes back on line
First 3 minutes of filter output diverted to backwash recovery tank in order to avoid turbidity spike contaminating clear water storage.

3.1 Corrective action

3.1.1 Individual Filter Failure

On occasions, the turbidity of a particular filter will appear to drift above the normal operating level. When this occurs, the operator will carry out the following investigation.

On the SCADA system, check the head loss trend for the filter in question. If this shows rapid deterioration, check the previous trends for that filter. Place the filter into manual backwash and physically observe the backwash to determine of there are any signs or sounds that would indicate a problem with the backwash sequence or equipment. O & M should be contacted if any equipment needs attention.

If the head loss trend has slowly increased since backwash and then appears to level off, and the filter displays a sudden rise in turbidity, this is a sign that breakthrough is occurring. In this instance the filter must be placed into manual backwash and subsequent performance closely monitored. If the filter repeats the breakthrough behavior then the filter will be taken off line and the individual system inspected.

If head loss of not excessive, and the pattern is normal, then the turbidimeter must be suspected of malfunction. The meter should be inspected, bled and cleaned. The last calibration record should be examined and if necessary, a new calibration performed. A manual laboratory test will be performed for comparison.

If the turbidimeter is in order and head loss in normal then the flow history (including UFRV's) of the filter should be considered. Sudden changes in flow will cause particle shear from filter media and this will of course increase turbidity. Also, clumping of filter media can contribute to breakthrough. In the first instance the history of the filter cell flow meter should be checked as well as the operation of the flow control valve.

As a last resort, the filter should be drained and the media inspected and cleaned if necessary. The nature of the particles providing the turbidity can be determined by microscopic examination. This task can be carried out by Scientific Services.

3.1.2 Collective Filter Failure

From time to time, all turbidimeters may indicate an upward trend from normal operation. When this occurs, the operator will carry out the following investigation.

Check the pH of the dosed water on the SCADA system and carry out a manual check also. Abnormal pH will indicate the dosing process has failed. Refer procedure OM-01-209 "Molendinar Dosed Water pH". In addition to the steps indicated there, a check of the polymer dosing and filter aid dosing systems should be made (if they are in use). The Operator MUST verify that dosing pumps in use are actually working and that the chemical is reaching it intended destination.

If the dosing process appears to be in order, inspect the display panels on all the turbidimeters for any message that indicates malfunction. Laboratory turbidity tests must be carried out to verify the readings from the on line instrument/s.

Check the raw water (including the recycled backwash water) for changes in pH, colour, turbidity, suspended solids and manganese. Significant alteration on the character of the raw water will involve re-optimization of the dosing regime, perhaps involving jar tests.

Check the raw water flow meter. Since dosing of most chemicals is flow paced, a significant drift in this meter can cause product deterioration. The meter should be bled as a first check and calibrated if necessary.

Check the quality of the recycled water. Deterioration in recycled water quality can mean the dosing regime is inadequate. Check also that sludge transfer from the bottom of the wash water recovery tanks to sewer is occurring during the settling phase.

Sudden flow increases can cause shearing of debris from filter media. If this is occurring, the operator will reduce flow to stabilize breakthrough and then slowly increase up to the desired level. It is preferable to choose lower output of high quality than higher output of compromised quality.

Carry out a laboratory pH and chlorine test on the filtered water if pre chlorination is in use. Excessive dosing of chlorine can drive the pH downwards possibly affecting the coagulation process.

When plant turbidity has increased beyond normal operating levels and the cause is either not obvious or will take considerable time to control then;

HELP WILL BE SOUGHT IMMEDIATELY. The help may involve phone advice or calling in of extra personnel. Remember, when turbidity increases, there are more particles in the water and in the absence of information to the contrary, these particles are assumed to present a health risk to the consumers.

3.1.3 Critical Limits

The Australian Drinking Water Guidelines recommend a turbidity of <1 N.T.U. in water that will undergo disinfection. The Molendinar Water Plant is capable of regularly producing filtered water that gives a reading of less than 0.1 NTU. This reading is not verified by laboratory tests that show a turbidity of 0.1 to 0.2 NTU due to the difference in sensitivity of the lab instruments. Nevertheless, the operator will be guided by the "on line" instruments, which operate around the 0.05 NTU level under ideal conditions. From the point of view of process control, it is the trend of this "on line" turbidity that is important, as much as its absolute value. Given that rising turbidity can be associated with increased health risk, every effort must be made to bring filtered water turbidity excursions under control as quickly as possible.

The Filtration process at Molendinar is a CRITICAL CONTROL POINT and therefore the following CRITICAL LIMITS apply.

If the turbidity of the filtered water As per the on line instruments reaches an average of 0.2 NTU (for all filters) for more than 5 hours the PLANT WILL BE SHUT DOWN until the problem has been rectified.

If the average turbidity of the plant filters exceeds 0.3 for more than 2 hours, the PLANT WILL BE SHUTDOWN until the problem has been rectified.

If the problem has been identified **and rectified,** a turbidity of greater than 0.3 will be tolerated as the plant regains normal function over the next few hours (provided the condition of the raw water is not deteriorating).

Any single filter that yields turbidity of greater than 0.3 for more than 2 hours will be taken off line until functional and a report completed.

ANY excursion above 0.2 NTU that lasts for more than 2 hours will require a report to the Senior Operator and a HACCP excursion form OM1101 will be forwarded.

Any decision to ignore shut down limits must be made by the Manager Operations & Maintenance. If the Manager is unavailable the Coordinator of Water and Wastewater or the Director of Gold Coast Water will make the decision.

In deciding whether to continue water production, the Manager will consider the following:

The condition of the raw water and the associated risk to consumers: Have recent bacterial counts been normal? Is the turbidity typical? (high turbidity from rain may mean increased protozoans in the raw water), what are the manganese levels in the raw water?, what is the colour of the filtered water? Are conditions stable.

The condition of the recycle stream. Have bacterial and algal counts been typical and stable? Does the recycle have a typical appearance (colour, turbidity)? Historically, Hinze dam has very low bacterial counts (avg of 3 cfu/100ml faecals) and the major source of faecals into the plant comes from the recycled water, which may be slightly contaminated by bird life. At Molendinar, faecal counts of 20 cfu/100ml are typical in the recycle stream. There will not be sufficient time to carry out bacterial tests in acute failure situations so the operator should physically inspect the clarifiers and recycle process for any unusual signs.

The manager may call for a microscopic examination of the filtered water to determine the nature of the turbidity (eg sand, clay, algae).

How far above the Critical Control Limit the water is and how long the plant will take to return to normal performance.

Uncertainty about risk should lead the manager to withhold supply as a precaution. Declaration of an incident (procedure QP-19) would then be a consideration. ANY staff member can declare an incident if they have reason to believe the risk to public safety is or will soon be compromised. Incident teams will consist of various experts who will determine a response suitable for the features of the specific turbidity failure.

Shutting down the plant is an undesirable option therefore as a last resort, the Duty Operator may consider trying bringing turbidity under control by reducing flow from the filter/s. If this is successful in lowering the turbidity, then shutdown may be avoided (again, provided the risk level of the raw water has not increased). However, it is obvious that reduced flow may lead to customer water shortages and still does not address the underlying cause of the initial turbidity incident.

During a turbidity incident, the Operator will also check the turbidity of the water leaving the reservoirs. This water has a higher turbidity than filtered water due to the formation of insoluble inorganic material following post lime pH correction. A typical figure is around 0.3 NTU (using laboratory bench top unit) so it is possible a significant filter turbidity failure will not be easily detected at this point. Nevertheless, the turbidity of this water should be recorded and reported.

As a matter of routine, the Senior Operator will review the 24-hour turbidity trends each weekday and will ensure that any necessary excursions are written (OM-1101). The Coordinator of Water and Wastewater will make trend inspections on a random basis at least weekly. Internal quality auditors will also make a random check of turbidity trends during internal quality audits of this procedure. Any turbidity excursions that have not been properly reported will be drawn to the attention of the Manager Operations & Maintenance. Turbidity records for at least the previous 12 months will be held.

4 Reporting and Verification

All HACCP excursion reports (form 1101) will be forwarded within 24 hours to:

Director Gold Coast Water.
Manager Operations & Maintenance.
Manager Service Delivery
Coordinator Product Quality
Coordinator Water & Wastewater

Failing to report HACCP excursions is a serious matter. Operators, who fail to notify management of excursions, are exposed to the possibility of personal liability in the event of public health consequences. Once excursions are reported, it is the responsibility of the Management team to consider if the excursion represents a need for a change in risk management measures.

The HACCP reporting system ensures that there is a paper trail for any event exceeding Critical Limits.

To verify that excursions are duly completed, internal HACCP auditors have access to the following information:

24 Hour Turbidity trend records
24 hour dosed water pH trends.
24-hour chlorine demand trends.
Daily manual checks by the Operators.
Routine checks by Scientific Services
Turbidity results from key locations in the distribution system.

Appendix B

Model water safety plans

The following represent 'model' water safety plans for a range of technologies including community-managed point sources (boreholes, springs, dug wells and rainwater) and piped water supplies as well as mechanised boreholes connected to distribution systems and utility distribution systems. These are laid out in tables that provide the basis of the information required. This format, however, does not imply that this is how water safety plans must be developed.

For some of the hazard events, the risk will vary with season. However, the same categories are used as in other water safety plans for consistency. The risk should be interpreted as an overall relative frequency of occurrence. It should also be noted that for some hazards (e.g. priming water) the risk refers to the probability of the hazard occurring if the practice is followed and should not be taken as an overall assessment of probability of using priming water of all handpumps.

Model plans are presented, in table form, and are followed by information on verification for:

- boreholes fitted with handpumps;
- protected springs not connected to piped water supplies;
- dug wells;
- mechanised boreholes;
- rainwater collection no disinfection as standard;
- a utility distribution system; and
- a community managed distribution system.

B1 BOREHOLES FITTED WITH HANDPUMPS

Table B.1: Model water safety plan for boreholes fitted with handpumps.

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Ingress of contaminated surface water directly into borehole	Poor wellhead completion	Unlikely/ Major	Proper wellhead completion measures	1m concrete apron around wellhead; lining extends 30cm above the apron; drainage ditches in place	Lining stops at ground level. Apron damaged or cracked. Ditches full, faulty or absent	Sanitary inspection	Monthly	Community operator	Extend lining Repair apron Clean and repair drainage ditches
Ingress of contaminants due to poor construction or damage to the lining	Poorly maintained welllhead completion	Moderate/ Major	Proper wellhead completion	Top 5 metres of the annulus sealed Rising main in good condition	Annulus sealed for less than 3 metres. Colour changes Increased pumping required to raise water	Sanitary inspection Water clarity	Annual/as need arises	Community operator	Insert seal around annulus. Replace worn and corroded rising mains. Use materials less likely to corrode (e.g. plastics)
Borehole area is inundated with contaminated surface water	Lack of diversion ditches	Unlikely/ Major	Good drainage around wellhead	Diversion ditches of adequate size, in good condition and clear of rubbish	Ditch has rubbish or shows signs of wear	Sanitary inspection	Monthly	Community operator	Repair and clean ditch Increase size of ditch using

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Contamination introduced as handpump requires priming	Priming water contaminated	Almost certain/ Minor	Use direct handpump or clean water for priming	Water for priming stored in secure container	Priming water comes from contaminated source or is stored poorly	Inspection	Weekly	Community operator	Select handump that does not require pumping.
Contaminated shallow water drawn into aquifer	Hydraulic connection exists between shallow and deeper aquifers allowing draw-down into deeper aquifer	Almost certain/ Minor	Pumping regimes do not induce leaching	No evidence of drawdown of shallow groundwater	Evidence of shallow water drawdown (e.g. shallow wells start to dry up)	Colour Taste Odour Inspection	Annual/as need arises	Community operator	Set intake deeper (microbes) Water treatment (microbiol) blending (chemicals)
Leaching of microbial contaminants into aquifer	Leaching of faecal material from sanitation, solid waste, drains	Moderate/ Moderate	Provide adequate set-back distances defined on travel time	No sources of faecal material within set-back distance	Latrines/sewers built or solid waste dumps within separation distance	Inspection by community	Monthly	Community operator	Move pollutant sources, improve sanitation design, reduce sewer leakage
Groundwater contains naturally occurring chemicals	Geological setting means chemicals present at toxic levels	Moderate/ Moderate	Select groundwater with acceptable levels of natural chemicals	Water quality assessments indicate water quality is acceptable	Evidence of natural contaminants	Risk assessment of geological setting Water quality assessment	Before construction Periodic evaluation	Water development agency	Use alternative source Treatment of water

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Leaching of chemicals into groundwater	Leaching of chemicals from landfills, waste dumps, discharges to ground	Moderate/ Minor	Provide adequate set-back distances defined on travel time	No sources of chemicals within set-back distance	Pollutant discharges within set-back distance	Inspection by community	Monthly	Community operator	Move pollutant sources, improve pollution containment

B1.1 Verification plan

The majority of boreholes or tubewells fitted with handpumps are managed by communities. As a result, verification is likely to be undertaken by the surveillance agency rather than the supply managers. In this situation, verification is primarily geared towards ensuring that the water safety plan for boreholes/tubewells as a whole is effective rather than verifying the performance of an individual supply on a regular basis. In some urban areas, it may be possible to initiate relatively frequent monitoring with boreholes visited once or twice per year, with at least one sample taken in the wet season. In rural areas, verification is likely to be undertaken through a rolling programme of visits, with each supply visited every 2-5 years.

B1.2 Parameters for verification

Routine verification for microbial safety would primarily focus on testing for *E.coli*, with sanitary inspections also performed. If the handpump must be primed, the water used for priming should be tested in addition to the water in the borehole or tubewell.

A comprehensive analysis of the chemical quality of water should have been undertaken prior to commissioning of the supply. If this was not performed, then during the first verification visit the water should be tested for a range of chemical parameters. The specific parameters should be determined on the basis of an assessment of the likely presence of the chemical. These should always include consideration of arsenic, fluoride, nitrate and selenium. Subsequent verification may not include routine testing of chemicals, although in some case regular testing of chemicals known to be prone to temporal variation (for instance arsenic in shallow groundwater) may be warranted. In addition, verification should also include testing of physio-chemical parameters such as turbidity and electric conductivity.

Validation of control measures may include testing of other microbes, for instance faecal streptococci, as these are useful for groundwater known to be at risk of faecal contamination because they are more persistent than *E.coli*. Bacteriophages (for instance F-specific RNA phages) may be used to validate the control measures with respect to viral pathogens. It would not be expected that protozoa would represent a significant risk and if validation shows effective control for bacterial and viral pathogens, it is reasonable to assume that control would also be assured for protozoa.

Validation may also include analysis of nitrate, chloride and redox potential to validate control measures for draw-down of contaminated shallow groundwater into deeper groundwater and leaching of microbial or chemical contaminants into the aquifer. Tracer studies and hydrogeological models may be of value to validate control measures against draw-down or leaching of contaminants into the aquifer. If measures put in place to prevent or remove chemical contaminants, the chemical parameters should be included in the validation plan.

B2 PROTECTED SPRINGS NOT CONNECTED TO PIPED WATER SUPPLIES

Table B2: Model water safety plan for protected springs not connected to piped water supplies

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Contamination able to recharge spring in backfill area	Backfilled area becomes eroded	Moderate/ Major	Effective spring protection measures maintained	Area has grass cover; fence and diversion ditch in good condition No surface water uphill	Fence is broken Diversion ditch is damaged Surface water pools develop	Sanitary inspection	Monthly	Community operator	Repair fencing and ditches; drain surface water. Re-lay grass. Rehabilitate protective measures
Contamination in spring box or outlet	Spring box or retaining wall in poor condition, inundation from wastewater	Moderate/ Major to moderate	Maintenance of protection and drainage works	Masonry in good condition, wastewater ditch clear and in good condition	Masonry deteriorated; wastewater ditch blocked	Sanitary inspection	Monthly	Community operator	Repair masonry and covers; clear ditch

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Contaminated surface water causes rapid recharge	Surface water is allowed to form pools uphill and leads to rapid recharge of contaminants and limited attenuation	Moderate to Unlikely/ Major	Establish set-back distance based on travel time; drainage	No surface water, solid waste dumps uphill Faecal disposal methods available	Surface water close to springs Low sanitation coverage Poor solid waste removal Springs show rapid response in flow and quality to rainfall	Sanitary inspection Colour change response to rainfall	Monthly/ seasonally	Community operator	Drain surface water pools uphill of springs, promote improved sanitation and solid waste disposal
Contaminated shallow water drawn into aquifer	Hydraulic connection exists between shallow + deeper aquifers allowing draw-down into deeper aquifer	Almost certain/ Minor	Pumping regimes do not induce leaching	No evidence of drawdown of shallow groundwater	Evidence of shallow water drawdown (e.g. shallow wells start to dry up)	Colour Taste Odour Inspection	Annual/as need arises	Community operator	Set intake deeper (microbes) Water treatment (microbiol) blending (chemicals)

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Ingress of animal faeces	Animal husbandry uphill and close to the spring Animal damage to backfill area	Moderate/ Moderate	Set-back distance to Control animal husbandry; good fencing	No kraals or sheds in set-back distance; fence in good condition	Animal husbandry found within controlled area Fencing damaged or absent	Sanitary inspection	Monthly	Community operator	Remove animal sheds or kraals from uphill of spring or move to safe distance Repair or erect fences
Leaching of microbial contaminants into aquifer	Leaching of faecal material from sanitation, solid waste, drains	Moderate/ Moderate	Provide adequate set-back distances defined on travel time	No sources of faecal material within set-back distance	Latrines/sewers built or solid waste dumps within separation distance	Inspection by community	Monthly	Community operator	Move pollutant sources, improve sanitation design, reduce sewer leakage
Groundwater contains naturally occurring chemicals	Geological setting means chemicals present at toxic levels	Moderate/ Moderate	Select groundwater with acceptable levels of natural chems	Water quality assessments indicate water quality is acceptable	Evidence of natural contaminants	Risk assessment of geological setting Water quality assessment	Before construction Periodic evaluation	Water development agency	Use alternative source Treatment of water

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Leaching of chemicals into groundwater	Leaching of chemicals from landfills, waste dumps, discharges to ground	Moderate/ Minor	Provide adequate set-back distances defined on travel time	No sources of chemicals within set-back distance	Pollutant discharges within set-back distance	Inspection by community	Monthly	Community operator	Move pollutant sources, improve pollution containment

B2.1 Verification plan

The majority of protected springs not connected to a distribution system are managed by communities. As a result, verification is likely to be undertaken by the surveillance agency rather than the supply managers. In this situation, verification is primarily geared towards ensuring that the water safety plan for protected springs as a whole is effective rather than verifying the performance of an individual supply on a regular basis. In some urban areas, it may be possible to initiate relatively frequent monitoring with protected springs visited once or twice per year, with at least one sample taken in the wet season. In rural areas, verification is likely to be undertaken through a rolling programme of visits, with each supply visited every 2-5 years.

B2.2 Parameters for verification

Routine verification for microbial safety would primarily focus on testing for *E.coli*, with sanitary inspections also performed. A comprehensive analysis of the chemical quality of water should have been undertaken prior to commissioning of the supply. If this was not performed, then during the first verification visit the water should be tested for a range of chemical parameters. The specific parameters should be determined on the basis of an assessment of the likely presence of the chemical. These should always include consideration of arsenic, fluoride, nitrate and selenium. Subsequent verification may not include routine testing of chemicals, although in some case regular testing of chemicals known to be prone to temporal variation (for instance arsenic in shallow groundwater) may be warranted. In addition, verification should also include testing of physio-chemical parameters such as turbidity and electric conductivity.

Validation of control measures may include testing of other microbes, for instance faecal streptococci, as these are useful for groundwater known to be at risk of faecal contamination because they are more persistent than *E.coli*. Bacteriophages (for instance F-specific RNA phages) may be used to validate the control measures with respect to viral pathogens. It would not be expected that protozoa would represent a significant risk and if validation shows effective control for bacterial and viral pathogens, it is reasonable to assume that control would also be assured for protozoa.

Validation may also include analysis of nitrate, chloride and redox potential to validate control measures for draw-down of contaminated shallow groundwater into deeper groundwater and leaching of microbial or chemical contaminants into the aquifer. Tracer studies and hydrogeological models may be of value to validate control measures against draw-down or leaching of contaminants into the aquifer. If measures put in place to prevent or remove chemical contaminants, the chemical parameters should be included in the validation plan.

B3 DUG WELLS

Table B.3: Model water safety plan for dug wells

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Ingress of contaminated surface water directly into well	Well does not have a cover; lining stops at ground level; faulty or absent apron; drainage ditches faulty or absent	Moderate/ Major	Proper wellhead completion with raised wellhead, cover and apron. Good drainage	Well covered Lining extends 30cm above the apron. Apron with radius of 1.5m around well. Drainage ditches in good condition	Lack of cover on well; lining stops at ground level; apron damaged or cracked; ditches full, faulty or absent	Sanitary inspection	During construction Monthly	Water development agency Community operator	Provide cover on well Extend lining. Repair apron. Clean and repair drainage ditches.
Ingress of contaminants due to poor construction or damage to the lining	Entry of contamination in top few metres of dug well because of cracks in lining or poor sealing of lining	Moderate/ Minor	Proper construction and use of a mortar seal on lining	Lining in good condition; no signs of weep holes in lining during rainfall	Well lining is pitted, evidence of seepage into well during rainfall	Sanitary inspection	Seasonal	Community operator	Improve well lining

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Animal damage allows contamination routes to develop	Animals not excluded from immediate wellhead	Likely/ Moderate	Fencing	Fence in good condition	Lack of fence or faults in fence	Sanitary inspection	Monthly	Community operator	Repair or install fence
Contamination introduced by buckets	Handpump or other sanitary means of abstraction not installed or non-functioning	Almost certain/ Major	Install and maintain handpump or other sanitary means of abstraction	Abstraction by handpump or other sanitary method in good working order	Lack of handpump or other sanitary means of withdrawal	Sanitary inspection	Monthly	Community operator	Install or repair handpump or other sanitary means of withdrawal
Wellhead area is inundated with contaminated surface water	Lack of diversion ditches mean that source is not protected against flood events	Unlikely/ Major	Diversion ditches surround the dug well, designed	Diversion ditch clear of rubbish and in good condition	Ditch has rubbish or shows signs of wear	Sanitary inspection	Monthly	Community operator	Repair and clear ditches
Leaching of microbiol contaminants into aquifer	Leaching of faecal material from sanitation, solid waste, drains	Moderate/ Moderate	Provide adequate set-back distances defined on travel time	No sources of faecal material within set-back distance	Latrines/sewers built or solid waste dumps within separation distance	Inspection by community	Monthly	Community operator	Move pollutant sources, improve sanitation design, reduce sewer leakage

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Groundwater contains naturally occurring chemicals	Geological setting means chemicals present at toxic levels	Moderate/ Moderate	Select groundwater with acceptable levels of natural chemicals	Water quality assessments indicate water quality is acceptable	Evidence of natural contaminants	Risk assessment of geological setting Water quality assessment	Before construction Periodic evaluation	Water development agency	Use alternative source Treatment of water
Leaching of chemicals into groundwater	Leaching of chemicals from landfills, waste dumps, discharges to ground	Moderate/ Minor	Provide adequate set-back distances defined on travel time	No sources of chemicals within set-back distance	Pollutant discharges within set-back distance	Inspection by community	Monthly	Community operator	Move pollutant sources, improve pollution containment

B3.1 Verification plan

The majority of protected dug wells are managed by communities. As a result, verification is likely to be undertaken by the surveillance agency rather than the supply managers. In this situation, verification is primarily geared towards ensuring that the water safety plan for dug wells as a whole is effective rather than verifying the performance of an individual supply on a regular basis. In some urban areas, it may be possible to initiate relatively frequent monitoring with dug wells visited once or twice per year, with at least one sample taken in the wet season. In rural areas, verification is likely to be undertaken through a rolling programme of visits, with each supply visited every 2-5 years.

B3.2 Parameters for verification

Routine verification for microbial safety would primarily focus on testing for *E.coli*, with sanitary inspections also performed. If a handpump is used that must be primed, the water used for priming should be tested in addition to the water in the dug well.

A comprehensive analysis of the chemical quality of water should have been undertaken prior to commissioning of the supply. If this was not performed, then during the first verification visit the water should be tested for a range of chemical parameters. The specific parameters should be determined on the basis of an assessment of the likely presence of the chemical. These should always include consideration of arsenic, fluoride, nitrate and selenium. Subsequent verification may not include routine testing of chemicals, although in some case regular testing of chemicals known to be prone to temporal variation (for instance arsenic in shallow groundwater) may be warranted. In addition, verification should also include testing of physio-chemical parameters such as turbidity and electric conductivity.

Validation of control measures may include testing of other microbes, for instance faecal streptococci, as these are useful for groundwater known to be at risk of faecal contamination because they are more persistent than *E.coli*. Bacteriophages (for instance F-specific RNA phages) may be used to validate the control measures with respect to viral pathogens. It would not be expected that protozoa would represent a significant risk and if validation shows effective control for bacterial and viral pathogens, it is reasonable to assume that control would also be assured for protozoa.

Validation may also include analysis of nitrate, chloride and redox potential to validate control measures for draw-down of contaminated shallow groundwater into deeper groundwater and leaching of microbial or chemical contaminants into the aquifer. Tracer studies and hydrogeological models may be of value to validate control measures against draw-down or leaching of contaminants into the aquifer. If measures put in place to prevent or remove chemical contaminants, the chemical parameters should be included in the validation plan.

B4 MECHANISED BOREHOLES

Table B4: Model water safety plan for mechanised boreholes

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Ingress of contaminated surface water directly into borehole	Poor wellhead completion	Unlikely/ Major	Proper wellhead completion measures	1m concrete apron around wellhead; lining extends 30cm above the apron; drainage ditches in place	Lining stops at ground level. Apron damaged or cracked. Ditches full, faulty or absent	Sanitary inspection	Monthly	Operator	Extend lining Repair apron Clean and repair drainage ditches
Ingress of contaminants due to poor construction or damage to the lining	Poorly maintained welllhead completion	Moderate/ Major	Proper wellhead completion	Top 5 metres of the annulus sealed Rising main in good condition	Annulus sealed for less than 3 metres. Colour changes Increased pumping required to raise water	Sanitary inspection Water clarity CCTV	Monthly	Operator	Insert seal around annulus. Replace worn and corroded rising mains. Use materials less likely to corrode (e.g. plastics)
Borehole area is inundated with contaminated surface water	Lack of diversion ditches	Unlikely/ Major	Good drainage around wellhead	Diversion ditches of adequate size, in good condition and clear of rubbish	Ditch has rubbish or shows signs of wear	Sanitary inspection	Weekly	Operator	Repair and clean ditch Increase size of ditch using

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Contaminated shallow water drawn into aquifer	Hydraulic connection exists between shallow and deeper aquifers allowing draw-down into deeper aquifer	Almost certain/ Moderate	Control pumping regimes Set intake at depth	No evidence on induced leakage	Evidence of shallow water drawdown (e.g. shallow wells start to dry up)	Colour (appearance) Taste Odour Electric conductivity	Weekly	Operator	Set intake deeper (microbes) Water treatment (microbiol) or blending (chemicals)
Rapid recharge by rivers, streams and ponds	Hydraulic connection exists between surface water and aquifers	Unlikely/ Major to Catastrophic	Set intake at greater depth	Rapid recharge does not occur or cannot reach intake	Evidence of rapid recharge from surface water bodies	Surface water levels Colour Electric conductivity	Daily	Operator	Set intakes at greater depth or modify pumping regimes
Pumping leads to increased leaching of contaminants	Pumping induces increased leaching of chemicals	Unlikely/ Moderate	Pumping regime	Leaching of contaminants is within predicted range	Evidence of increased leaching of contaminants	Monitoring of key contaminants of concern Hydro-chemical models	Monthly	Operator	Modify pumping regime Treatment

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Pumping increases safe distances beyond current protection zone boundaries	Pumping increases cone of depression extends minimum travel time distance beyond protection zone	Unlikely/ Moderate	Protection zones	Protection zones include influence of drawdown on groundwater flow	Drawdown increases distance equivalent to travel time set	Water table levels surrounding borehole when pumping	Annual	Operator	Extend groundwater protection zone to account of the change in distance
Back-siphonage from pipe into borehole	No backflow preventer installed	Likely/ Minor	Backflow preventer on mains	Backflow preventer installed	Lack of backflow preventer	Inspect pumping works	Installations Periodic checks	Constructor Operator	Backflow preventer installed
Failure in disinfection process	Disinfection process fails	Unlikely/ Major catastrophic	Effective chlorination with contact time	Ct value adequate and residual produced	Lack of residual	Monitoring chlorine dosing and residual	Daily/hourly	Operator	Take pump off-line and repair disinfection unit

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Mobilisation of toxic chemicals and elution of viruses	Changes in land-use and increased recharge through irrigation leads to mobilisation and elution	Rare/ Minor to moderate	Land-use control, in particular managing irrigation	Little artificial recharge through irrigation, pH and Eh of water stable	Significant changes in land-use Increased use of irrigation	Land-use; pH of groundwater Redox (Eh)	Weekly	Operator	Reduce artificial recharge
Leaching of microbiol contaminants into aquifer	Leaching of faecal material from sanitation, solid waste, drains	Moderate/ Moderate	Protection zones and set-back distances	Lateral separation defined on basis of travel times and hydrogeology	Latrines/sewers built or solid waste dumps within separation distance	Sanitary inspection; inspection of protection zone, electric conductivity, sewer leakage	Monthly	Operator	Remove pollutant sources, improve sanitation design, reduce sewer leakage, insert cut-off walls around sewers
Groundwater contains naturally occurring chemicals	Geological setting means chemicals present at toxic levels	Moderate/ Moderate	Source selection	Use of groundwater with no natural chemical at harmful levels	Evidence of natural contaminants	Risk assessment of geological setting Initial assessment of water quality	Before installation	Constructor	Use alternative source Treatment

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Agricultural pollution: nitrate	Use of inorganic or organic fertilisers, stock density	Unlikely/ Minor	Protection zone	Nitrate vulnerable zones defined for aquifer prevent excessive leaching	Evidence of increasing nitrate levels	Monitoring of nitrate in groundwater Monitor fertiliser applications Monitor stock densities	Monthly	Supplier Environment agency	Control of fertiliser applications Blending of drinking water
Agricultural pollution: pesticides	Pesticides leached into the groundwater	Unlikely/ Minor	Protection zone	Pesticide applications controlled in recharge area	Evidence of increasing pesticides in water Evidence of pesticide application at high-risk locations and times	Monitor pesticide applications	Monthly	Supplier Environment agency	Control of pesticide applications
Leaching of chemicals from landfill sites into groundwater	Leaching of chemicals from landfills, waste dumps, industrial discharges to ground	Moderate/ Minor	Protection zone	Landfills are sanitary and properly sealed Landfill presence controlled on basis of travel times and hydrogeology	Monitoring around pollutant sources indicate increasing pollution migration	Monitor for key contaminants around pollutant sources Monitoring bills of lading	Weekly/daily	Waste Managers Environment agency Supplier	Move pollutant sources, improve pollution containment, monitoring network around pollutant sources

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Pathogens from hospital wastes contaminate groundwater	Poor disposal of hospital wastes allows direct ingress of leaching into groundwater	Unlikely/ Catastrophic	Proper hospital waste disposal	Hospital wastes with pathogenic material incinerated	Hospital waste disposal in dumps or ground containers	Monitor hospital waste disposal methods	Daily	Water supplier Health authorities	Ensure all pathogenic material incinerated or sterilised
Pollution from urban areas contaminates groundwater	Poorly sealed drains cause recharge of groundwater	Moderate/ Minor	Protection zones	Drainage water unable to recharge groundwater	Poorly constructed drains increase potential for recharge	Inspection	Operator	Weekly	Ensure all drains properly sealed in recharge or vulnerable areas
Industrial discharges contaminated groundwater	Poorly disposed of industrial waste can inundate groundwater source or leach into aquifer	Moderate/ Minor	Waste containment and treatment	Effective disposal methods prevent spills and leaching	Waste disposal methods do not provide security against inundation and leaching	Monitor containment methods at industrial sites	Supplier Environment agency	Monthly	Ensure all industrial waste is properly contained and treated at the site

B4.1 Verification plan

Mechanised boreholes are usually connected to distribution systems and may be managed by a utility or local Government water supplier, a water user association or water user group or by communities. Where boreholes are operated by a water supplier, it would be expected that they would undertake much of the routine verification, although they may seek assistance in validation. Verification should be carried out on a regular basis and in particular the potential for seasonal deterioration in water quality taken into account when designing a verification programme. Verification data should be reviewed in the audits undertaken by the surveillance agency.

In supplies managed by the community or where water user association or water user groups then verification may be undertaken by the surveillance agency. In this situation, verification is primarily geared towards ensuring that the water safety plan for mechanised boreholes as a whole is effective rather than verifying the performance of an individual supply on a regular basis. In some urban areas, it may be possible to initiate more regular monitoring and for boreholes to be visited once or twice per year, with at least one sample taken in the wettest season. In rural areas, verification is likely to be undertaken through a rolling programme of visits, with each supply visited every 2-5 years.

B4.2 Parameters for verification

Routine verification of microbial safety would primarily focus on testing for *E.coli* and turbidity, with sanitary inspections also performed. If the pump must be primed., the water used for priming should be tested in addition to the water in the borehole. Close-circuit television (CCTV) should also be included in verification as a means of undertaking an inspection of the integrity of the casing of the borehole. Audits of maintenance records of the borehole, as well as other key functions such as drainage, should be carried out during verification. Audits may also be undertaken of any industries discharging into the environment within a distance identified as being of concern.

A comprehensive analysis of the chemical quality of water should have been undertaken prior to commissioning of the supply. If this was not performed, then during the first verification visit the water should be tested for a range of chemical parameters. The specific parameters should be determined on the basis of an assessment of the likely presence of the chemical. These should always include consideration of arsenic, fluoride, nitrate and selenium. Subsequent verification should include routine testing of chemicals known to be present and that are known to be prone to temporal variation. In addition, verification should also include testing of physio-chemical parameters such as electric conductivity and redox potential.

For boreholes operated by utilities, pathogen assessments should be considered as a key component of validation. This should include assessing risks from key reference pathogens and also undertaken studies to assess whether these are present. Validation may also include testing of other indicator organisms, such as bacteriophages (for instance F-specific RNA phages) to validate the control measures with respect to viral pathogens. Suitable organisms (for instance *Clostridium perfringens*) should be identified for protozoan pathogens.

Validation may also include analysis of a range of chemicals for which control measures are identified and in areas where there is potential for leaching of microbial or chemical contaminants into the aquifer. Tracer studies and hydrogeological models may be of value to validate control measures for draw-down and leaching of contaminants into the aquifer.

B5 RAINWATER COLLECTION, WITH NO DISINFECTION AS STANDARD

Table B5: Model water safety plan for rainwater collection no disinfection as standard

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Bird and animal droppings found on roof or in guttering	Roof is not cleaned properly or regularly allows build-up of faecal material	Likely/ Minor	Cleaning of roof and gutters	Roof is clean before rainfall	Roof dirty as rainfall collection starts	Sanitary inspection	Before rains	Owner/ Operator	Clean roof regularly
Trees overhang the collection tank	Overhanging branches allow birds and animals to gain access to roof	Likely/ Minor	Tree surgery	Trees branches do not overhand roof	Branches encroach on roof	Sanitary inspection	Annual	Owner/ Operator	Trim branches

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Animals and birds can enter the tank	Inspection covers and vents open or improperly sealed	Likely/ Major	Ensure all openings on tank are bird and animal proof	Inspection covers fitted and locked, vents have mesh	Inspection cover damaged, not in place, mesh damaged or not in place	Sanitary inspection	Annual	Owner/ Operator	Install or repair inspection covers and vents mesh
Tank dirty or sediment accumulates	Poor cleaning of tank	Unlikely/ Moderate	Cleaning of tank	Tank cleaned regularly and disinfected annually	Dirt seen inside tank Water appears turbid	Sanitary inspection Appearance	Annual	Owner/ Operator	Cleaning of tank, removal of sediment, disinfection
First flush of water can enter tank	First flush of water from roof is not diverted and so enters tank	Moderate/ Major	Foul-flush diversion unit	Foul-flush system in place and used correctly	Lack of foul-flush system Poor operation of foul-flush system	Sanitary inspection Colour Odour	On installation, then annual	Owner/ Operator	Install foul-flush system and train users
Unhygienic withdrawal of water allows contamination to enter	Water withdrawn using buckets which introduce contamination	Almost certain/ Minor	Install tap or other sanitary means of withdrawal	Tap in place to allow easy withdrawal of water	Lack of tap	Sanitary inspection	On installation	Owner/ Operator	Install tap with intake at least 5cm from base of tank

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Tank is damaged or allows contaminated surface water or groundwater to enter	Tank has cracks and other damage	Likely/ Minor	Structural integrity of tank	Tank set above ground and in good condition	Cracks in tank structure	Sanitary inspection	Annual	Owner/ Operator	Effect repairs
Roof material introduced into tank	Collection surface is soft and allows material to be leached into the tank	Likely/ Minor	Only use hard surfaces for rainwater collection	Collection from impermeable surfaces	Collection from thatch and other soft surfaces	Sanitary inspection	At installation	Owner/ Operator	Replace roof material
Water is not filtered	Water enters into tank with no filtration	Likely/ Minor	Filter installed and maintained	Tanks have working filter installed to remove debris	Lack of filter, increased turbidity	Sanitary inspection Turbidity Colour	Annual	Owner/ Operator	Install filter Clean filter
Leaching of chemical from roof material into water	Roof material contains lead or other harmful chemicals	Unlikely/ Minor	Materials for rainwater collection approved	Roof material should not contain lead or other harmful substances	Roof material known to contain lead or other harmful chemicals	Inspection of materials	At installation	Owner/ Operator	Use lead-free roofing material

B5.1 Verification plan

The majority of rainwater collection systems are operated by households or communities. As a result, verification is likely to be undertaken by the surveillance agency. In this situation, verification is primarily geared towards ensuring that the water safety plan for rainwater collection as a whole is effective rather than verifying the performance of an individual supply. Verification is likely to be undertaken through a rolling programme of visits, although not every individual supply may be visited.

B5.2 Parameters for verification

Routine verification would primarily focus on sanitary inspection with some testing of *E.coli* and turbidity. If not previously carried out prior to commissioning, during the first verification visit the water should be tested for a range of chemical parameters. The specific parameters should be determined on the basis of an assessment of the likely presence of the chemical.

Validation of control measures may include testing of other microbes, for instance faecal streptococci and bacteriophage. Validation may also include analysis of lead from some roofs which use tanalised timber. Other chemicals may be included if it is considered they are likely to be present and may vary over time.

B6 UTILITY DISTRIBUTION SYSTEM

Table B6:Model water safety plan for a utility distribution system

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Water entering distribution is contaminated	Treatment failure	Moderate/ Catastrophic	Treatment is effective	Optimised treatment	Treatment plant moves out of compliance	Ct value Residual disinfectant) Particle count Turbidity Inspection	Hourly/daily	Operations staff	Take treatment unit off-line and apply appropriate corrective action
Microbial contamination of service reservoir	Birds/ animal contamination of service reservoirs	Unlikely/ Catastrophic	Ensure service reservoirs are bird and animal proof	All vents covered, inspection covers in place and locked No tree branches overhang reservoir. Fence around tank	Vent or inspection covers not in place or damaged; fence damaged, tree branch encroach on tank	Sanitary inspection	Daily	Operations staff	Repair and replace damaged vents and inspection covers. Cut back tree branches.

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Microbial contamination derived biofilm and/or sediment in service reservoir	Biofilm and sediment may slough or be disturbed.	Likely/Minor	Manage biofiml and sediment	Interior of reservoir is clean and sediment is minimised and undisturbed	Biofilm develops, increase in chlorine consumption	Sanitary inspection, chlorine residuals, turbidity Biofilm coupons	Daily	Operations staff	Take tank off-line during cleaning and flushing. Flush mains after completion with chlorinated water
Ingress of contaminated water into service reservoir	Leaks in tanks below ground or where stagnant water collects around base	Unlikely/ Minor	Structural integrity and drainage	Tank structure sound with no cracks and drainage channels in good condition	Drainage channels blocked, cracks develop in tank structure	Sanitary inspection	Daily	Operations staff	Clear drainage channels. Take tanks off-line for repairs. Flush tank and distribution before re-commissioning
Contamination enters distribution system at valves at service reservoir	Valve boxes become inundated by contaminated surface water	Moderate/ Major (depends on location and population served)	Structural integrity and drainage	Valve box with permeable base and adequate drainage	Water build up within valve box; drainage damaged or requires cleaning	Sanitary inspection	Daily	Operations staff	Repair leaks drains and valve box. Repair valve if showing signs of wear

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Contamination enters distribution system at major sluice valves in distribution	Major sluice valves are inundated by contaminated water	Moderate/ Major (depends on location and population served)	Structural integrity and maintenance of valve boxes	Valve box with permeable base and adequate drainage	Water build up within valve box, damage to drains or drains in need of cleaning	Sanitary inspection, chlorine residual, turbidity	Daily	Operations staff	Repair leaks drains and valve box. Repair valve if showing signs of wear.
Contamination enters distribution system from major institutions	Intermittence or pressure fluctuations lead to back-siphonage from large institutions into mains.	Likely/ Moderate	Ensure backflow preventers (one-way valves) installed Institutional WSP developed	Backflow preventers function correctly and water quality management plan developed and followed	Backflow preventer absent/faulty Absence of a water quality management plan	Sanitary inspection of backflow preventers	Weekly/ monthly	Operations staff	Utility to provide advice to institution on water quality management plan. Repair to backflow preventers
Contamination results from cross-connections to sewer system	Leaking sewer lie to close to mains and allows pathogens to directly enter the supply	Likely/ Catastrophic (depends on location and population served)	Good design and sewer and mains leakage control programmes	Systems designed to prevent cross-connection under all circumstance	Sudden chlorine loss, risk assessment indicates elevated risk	Chlorine residual, turbidity, sanitary inspection/ risk model	Monthly	Operations (both water and sewerage	Leaks in water supply and sewer should be repaired rapidly; rehabilitation to improve hydrostatic pressure; cut-off walls in high-risk areas

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Back-siphonage of contaminated water	Leaks in pipe combined with drops in pressure (either intermittence or transient pressure waves) allow ingress of water containing pathogens from faecally-contaminated soils	Likely/ Moderate (depends on location and population served)	Reduce intermittence and limit potential for transient pressure waves by limiting direct connections on pumping mains	Piped water supply with leakage control programme and positive hydrostatic pressure Cut-off walls Limited water hammer	Sudden loss of chlorine, increase in turbidity, risk assessment indicates high risk	Chlorine residuals, turbidity, sanitary inspection/ risk model	Daily	Operations staff	Reduce intermittence. Leakage control programme. Where intermittence unavoidable, disinfection strategy developed. Cut-off walls constructed in high risk areas Reduce transient pressure waves
Contamination introduced during repairs on distribution system	Poor hygiene in repair work allows contamination to enter into the system	Moderate/ Catastrophic	Hygienic codes of practice for work on distribution mains	Hygiene code developed, available to all staff and followed	Evidence that hygiene code not followed	Turbidity Chlorine residuals Site inspection	Daily	Management/operations	Ensure that hygiene code is prepared and made available to all staff. Training in good hygiene for mains repair teams.

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Biofilm sloughing into drinking water	Biofilm develops because of high AOC content and lack of control strategy. Hydraulic changes (surges/water hammer) lead to sloughing	Moderate/ minor	Minimise biofilm formation (chlorination or use biologically stable water)	Little biofilm developed and limited risk of sloughing	Increases in turbidity, chlorine loss, changes in colour	Chlorine residual, colour, turbidity, odour, customer complaints, corrosion coupons	Daily	Operations	Replacement of high adherence pipe material, improve biological stability through optimised treatment, improve steady state flow

B6.1 Verification plan

Verification of utility supplies would usually be the responsibility of the utility that operates the system. Surveillance agencies should undertake regular audits of the supplier records and may undertake some independent testing of water quality. Verification should be ongoing and include regular testing, as well as periodically performing more extensive assessments and internal audits. The latter would typically be carried out on an annual basis.

Sampling should be spread throughout the system and standard operating procedures defined. This should include use of accepted sampling methods (for instance those defined by ISO). Sample numbers for microbial safety should be calculated on the basis of population served as shown in the table below.

Table B7: Recommended minimum sample numbers for faecal indicator testing in distribution systems

Population	Total number of samples/year
<5 000	12
5000 to 100 000	12 per 5000 head of population
>100 000-5000K	12 per 10 000 head of population plus an additional 120 samples
>500,000	12 per 100,000 head of population + an additional 180 samples

B6.2 Parameters for verification

Routine verification would primarily focus on testing for E.coli and turbidity, with sanitary inspections also performed. Other parameters may be identified as appropriate, for instance routine analysis of Clostridium perfingens of treatment performance. There should be regular verification of the chemical quality of source and final waters, with the parameters selected based upon an initial risk assessment. In the distribution system, testing of chemicals for verification may be less frequent and should be determined on the basis of a risk assessment.

Validation of control measures will, by preference, be based upon pathogen assessments using selected reference pathogens (e.g. *Cryptosporidium*, *E.coli* O157:H7 and rotavirus) and risk assessments performed to evaluate performance in relation to health-based targets. Validation may also use index organisms such as bacteriophages (for instance F-specific RNA phages) as surrogates for validate the control measures with respect to viral pathogens.

A comprehensive analysis of the chemical quality of water should have been undertaken prior to commissioning of the supply. If this was not performed, then during the first verification visit the water should be tested for a range of chemical parameters. The specific parameters should be determined on the basis of an assessment of the likely presence of the chemical. These should always include consideration of arsenic, fluoride, nitrate and selenium. Subsequent verification should include routine testing of chemicals known to be present and that are known to be prone to temporal variation. In addition, verification should also include testing of physio-chemical parameters such as electric conductivity and redox potential.

Validation may also include analysis of chemicals for which control measures have been defined, Tracer studies, hydrochemical and flow models may be of value to validate control measures in treatment works and to predict likely impact of contamination events within distribution systems. The measurement of AOC may also be considered if control measures are in place to reduce re-growth.

B7 COMMUNITY MANAGED DISTRIBUTION SYSTEM

Table B8: Model water safety plan for community managed distribution system

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Water entering distribution is contaminated	Failure at source (see spring, borehole WSP)	Moderate/ Catastrophic	Ensure source WSP adhered to	Optimised source protection (see spring/borehole WSP)	Source WSP indicates non-compliance	Sanitary inspection Turbidity Chlorine residual (if chlorinated)	Weekly/daily	Community operator	Take source off-line and apply appropriate corrective action (see appropriate WSP)
Microbial contamination of storage tank	Birds/ animal contamination of storage tanks	Unlikely/ Major	Make sure tank is animal and bird-proof	Vents covered, inspection covers in place and locked No tree branches overhang reservoir. Fence around tank	Vent or inspection covers not in place or damaged; fence damaged, tree branch encroach on tank	Sanitary inspection	Weekly/ Monthly	Community operator	Vents should be designed so as to prevent direct access and covered to prevent access from small birds and rodents. Tree branches should be cut-back and the site made secure.

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Ingress of contaminated water into storage tank	Leaks in tanks may lead to contamination. This may occur when tanks are either below ground or allow stagnant water to collect around base	Unlikely/ Minor	Structural integrity and drainage	Tank structure sound with no cracks and drainage channels in good condition	Drainage channels blocked, cracks develop in tank structure	Sanitary inspection	Monthly	Community operator	Clear and repair drainage channels. Take tank off-line to make repairs. Flush tank and distribution before re-commissioning
Contamination enters distribution system at major valves in distribution or storage tank	Major sluice valves are inundated by contaminated water	Moderate/ Major	Valve maintenance and drainage	Valve box with permeable base and adequate drainage	Water build up within valve box, damage to drains or drains in need of cleaning	Sanitary inspection, turbidity	Monthly	Community operator	Repair leaks drains and valve box. Repair valve if showing signs of wear Disinfect supply

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action
				Target	Action	What	When	Who	
Back-siphonage of contaminated water	Leaks in pipe combined with drops in pressure (either intermittence or transient pressure waves) allow ingress of water containing pathogens from faecally-contaminated soils	Likely/ Moderate (depends on location and population served)	Ensure that supply has sufficient water to meet demand and ensure all connections downstream of tanks	All connections on lines served by tank, leakage is low	Intermittence increases, leakage increases	Sanitary inspection, turbidity, chlorine residuals (if chlorinated	Daily/weekly	Community operator	Reduce intermittence. Leakage control programme.
Contamination introduced during repairs on distribution system	Poor hygiene in repair work allows contamination to enter into the system	Moderate/ Catastrophic	Hygienic codes of practice followed	Hygiene code developed and training provided to all people working on system	Evidence that hygiene code not followed	Turbidity Site inspection	As required	Community operator	

B7.1 Verification plan

Verification for community-managed piped distribution systems will depend on local resources. In developed countries, verification may be undertaken by some communities. However, in developing countries and in smaller community-managed supplies in developed countries, verification is likely to be undertaken by the surveillance agency. In this situation, verification is primarily geared towards ensuring that the water safety plan for community-managed distribution systems as a whole is effective rather than verifying the performance of an individual supply on a regular basis. In rural areas, verification is likely to be undertaken through a rolling programme of visits, with each supply visited every 2-5 years.

Within the system, sampling should be spread throughout the system and standard operating procedures defined. This should include use of accepted sampling methods (for instance those defined by ISO). Sample numbers for microbial safety should be calculated on the basis of population served as shown in the table below.

Table 9: Recommended minimum sample numbers for faecal indicator testing in distribution systems

Population	Total number of samples/year
<5 000	12
5000 to 100 000	12 per 5000 head of population

B7.1 Parameters for verification

Routine verification for microbial safety would primarily focus on testing for *E.coli*, with sanitary inspections also performed. A comprehensive analysis of the chemical quality of water should have been undertaken prior to commissioning of the supply. If this was not performed, then during the first verification visit the water should be tested for a range of chemical parameters. The specific parameters should be determined on the basis of an assessment of the likely presence of the chemical. These should always include consideration of arsenic, fluoride, nitrate and selenium. Subsequent verification may not include routine testing of chemicals, although in some case regular testing of chemicals known to be prone to temporal variation (for instance arsenic in shallow groundwater) may be warranted. In addition, verification should also include testing of physio-chemical parameters such as turbidity and electric conductivity.

Validation of control measures may include testing of other microbes, for instance faecal streptococci, as these are useful for groundwater known to be at risk of faecal contamination because they are more persistent than *E.coli*. Bacteriophages (for instance F-specific RNA phages) may be used to validate the control measures with respect to viral pathogens. Where the supply includes treatment of surface water, *Clostridium perfringens* should be included within validation to assess treatment performance in relation to risks from protozoan pathogens. Validation should also include analysis of relevant chemicals where control measures have been identified for chemical contaminants.

Appendix C

Sanitary Inspection Forms

I. **Type of Facility** PIPED WATER

1. General Information : Zone:
   : Area
2. Code Number
3. Date of Visit
4. Water samples taken? …….. Sample Nos. ………

II **Specific Diagnostic Information for Assessment**

(please indicate at which sample sites the risk was identified) Risk Sample No

	Risk	Sample No
1. Do any tapstands leak?	Y/N	………….
2. Does surface water collect around any tapstand?	Y/N	………….
3. Is the area uphill of any tapstand eroded?	Y/N	………….
4. Are pipes exposed close to any tapstand?	Y/N	………….
5. Is human excreta on the ground within 10m of any tapstand?	Y/N	………….
6. Is there a sewer within 30m of any tapstand?	Y/N	………….
7. Has there been discontinuity in the last 10 days at any tapstand?	Y/N	………….
8. Are there signs of leaks in the mains pipes in the Parish?	Y/N	………….
9. Do the community report any pipe breaks in the last week?	Y/N	………….
10. Is the main pipe exposed anywhere in the Parish?	Y/N	………….

Total Score of Risks ..../10

Risk score: 9-10 = Very high; 6-8 = High; 3-5 = Medium; 0-3 = Low

III **Results and Recommendations:**

The following important points of risk were noted:
(list nos. 1-10)

Signature of Health Inspector/Assistant:

Comments:

I. **Type of Facility** PIPED WATER WITH SERVICE RESERVOIR

1. General Information : Zone
   : Area
2. Code Number
3. Date of Visit
4. Water samples taken? …….. Sample Nos. ………

II Specific Diagnostic Information for Assessment

(please indicate at which sample sites the risk was identified) Risk Sample No

	Risk	Sample No
1. Do any standpipes leak at sample sites?	Y/N	………….
2. Does water collect around any sample site?	Y/N	………….
3. Is area uphill eroded at any sample site?	Y/N	…………..
4.Are pipes exposed close to any sample site?	Y/N	………….
5. Is human excreta on ground within 10m of standpipe?	Y/N	………….
6. Sewer or latrine within 30m of sample site?	Y/N	………….
7. Has there been discontinuity within last 10 days at sample site?	Y/N	………….
8. Are there signs of leaks in sampling area?	Y/N	………….
9. Do users report pipe breaks in last week?	Y/N	………….
10. Is the supply main exposed in sampling area?		Y/N ………….
11. Is the service reservoir cracked or leaking?	Y/N	………….
12. Are the air vents or inspection cover insanitary?	Y/N	………….

Total Score of Risks ..../12

Risk score: 10-12 = Very high; 8-10 = High; 5-7 = Medium; 2-4 = Low; 0-1 = Very Low

III Results and Recommendations:

The following important points of risk were noted:
(list nos. 1-12)

Signature of Health Inspector/Assistant:
Comments:

I Type of Facility HYDRANTS AND TANKER TRUCKS

1. General information	Sub-Metro Community

2. Code Number:
3. Date of visit:
4. Is water sample taken?………
Sample No……
Thermotolerant Coliform Grade………

II Specific Diagnostic Information for Assessment

	Risk	
1. Is the discharge pipe dirty?		Y/N
2. Can the discharge pipe touch the ground?	Y/N	
3. Is the delivery nozzle dirty or in poor condition?	Y/N	
4. Are there any leaks close to the riser pipe of the hydrant?		Y/N
5. Is the base of the riser piped for the hydrant sealed with a concrete apron?	Y/N	
6. Is the tanker ever used for transporting other liquids?	Y/N	
7. Is the inside of the tanker dirty?	Y/N	
8. Does the tanker fill through an inspection cover on the tanker?	Y/N	
9. Is the discharge nozzle dirty or in poor condition?	Y/N	
10. Does the tanker leak?	Y/N	

Total Score of Risks …./10

Risk score: >8/10 = Very high; 6-8/10 = High; 4-7/10 = Intermediate; 0-3/10 = Low

III Results and Recommendations:
The following important points of risk were noted:
(list nos.1-10)
And the authority advised on remedial action

Signature of inspector:

I. **Type of Facility** GRAVITY-FED PIPED WATER

1. General Information : System name:
2. Code Number
3. Date of Visit
4. Water samples taken? …….. Sample Nos. ………

II **Specific Diagnostic Information for Assessment**

(please indicate at which sample sites the risk was identified) Risk Sample No

1. Does the pipe leak between the source and storage tank? Y/N ………….
2. Is the storage tank cracked, damaged or leak? Y/N ………….
3. Are the vents and covers on the tank damaged or open? Y/N ………….

	Risk	Sample No
4. Do any tapstands leak?	Y/N	………….
5. Does surface water collect around any tapstand?	Y/N	………….
6. Is the area uphill of any tapstand eroded?	Y/N	………….
7. Are pipes exposed close to any tapstand?	Y/N	………….
8. Is human excreta on the ground within 10m of any tapstand?	Y/N	………….
9. Has there been discontinuity n the last 10 days at any tapstand?	Y/N	………….
10. Are there signs of leaks in the main supply pipe in the system?	Y/N	………….
11. Do the community report any pipe breaks in the last week?	Y/N	………….
12. Is the main supply pipe exposed anywhere in the system?	Y/N	………….

Total Score of Risks …./12

Risk score: 10-12 = Very high; 8-10 = High; 5-7 = Medium; 2-4 = Low; 0-1 = Very Low

III **Results and Recommendations**:

The following important points of risk were noted:

(list nos. 1-12)

Signature of Health Inspector/Assistant:

I. **Type of Facility** DEEP BOREHOLE WITH MECHANISED PUMPING

1. General Information : Supply zone
   : Location:
2. Code Number
3. Date of Visit
4. Water sample taken? …….. Sample No. ……… FC/100ml ………..

II **Specific Diagnostic Information for Assessment**

	Risk	
1. Is there a latrine or sewer within 100m of pumphouse?		Y/N
2. Is the nearest latrine unsewered?	Y/N	
3. Is there any source of other pollution within 50m?	Y/N	
4. Is there an uncapped well within 100m?	Y/N	
5. Is the drainage around pumphouse faulty?	Y/N	
6. Is the fencing damaged allowing animal entry?		Y/N
7. Is the floor of the pumphouse permeable to water?	Y/N	
8. Does water forms pools in the pumphouse?	Y/N	
9. Is the well seal insanitary?		Y/N

Total Score of Risks …./9

Risk score: 7-9 = High; 3-6 = Medium; 0-2 = Low

III **Results and Recommendations**:
The following important points of risk were noted:
(list nos. 1-9)

Signature of Health Inspector/Assistant:

Comments:

I. Type of Facility BOREHOLE WITH HANDPUMP

1. General Information : Zone
   : Location
2. Code Number
3. Date of Visit
4. Water sample taken? …….. Sample No. ……… FC/100ml ………..

II Specific Diagnostic Information for Assessment

	Risk	
1. Is there a latrine within 10m of the borehole?		Y/N
2. Is there a latrine uphill of the borehole?	Y/N	
3. Are there any other sources of pollution within 10m of borehole? (e.g. animal breeding, cultivation, roads, industry etc)		Y/N
4. Is the drainage faulty allowing ponding within 2m of the borehole?		Y/N
5. Is the drainage channel cracked, broken or need cleaning?	Y/N	
6. Is the fence missing or faulty?	Y/N	
7. Is the apron less than 1m in radius?		Y/N
8. Does spilt water collect in the apron area?	Y/N	
9. Is the apron cracked or damaged?	Y/N	
10. Is the handpump loose at the point of attachment to apron?	Y/N	

Total Score of Risks …./10

Risk score: 9-10 = Very high; 6-8 = High; 3-5 = Medium; 0-3 = Low

III Results and Recommendations:

The following important points of risk were noted:
(list nos. 1-10)

Signature of Health Inspector/Assistant:

Comments:

I. **Type of Facility** PROTECTED SPRING

1. General Information : Zone:
   : Location
2. Code Number:
3. Date of Visit:
4. Water sample taken? …….. Sample No. ……… FC/100ml ………..

II **Specific Diagnostic Information for Assessment**

	Risk	
1. Is the spring unprotected?		Y/N
2. Is the masonry protecting the spring faulty?	Y/N	
3. Is the backfill area behind the retaining wall eroded?	Y/N	
4. Does spilt water flood the collection area?	Y/N	
5. Is the fence absent or faulty?	Y/N	
6. Can animals have access within 10m of the spring?	Y/N	
7. Is there a latrine uphill and/or within 30m of the spring?		Y/N
8. Does surface water collect uphill of the spring?		Y/N
9. Is the diversion ditch above the spring absent or non-functional?		Y/N
10. Are there any other sources of pollution uphill of the spring? (e.g. solid waste)	Y/N	

Total Score of Risks …./10

Risk score: 9-10 = Very high; 6-8 = High; 3-5 = Medium; 0-3 = Low

III **Results and Recommendations**:
The following important points of risk were noted:
(list nos. 1-10)

Signature of Health Inspector/Assistant:

Comments:

I. **Type of Facility** DUG WELL WITH HANDPUMP / WINDLASS

1. General Information : Zone:
   : Location
2. Code Number
3. Date of Visit
4. Water sample taken? …….. Sample No. ……… FC/100ml ………..

II **Specific Diagnostic Information for Assessment**

	Risk
1. Is there a latrine within 10m of the well?	Y/N
2. Is the nearest latrine uphill of the well?	Y/N
3. Is there any other source of pollution within 10m of well? (e.g. animal breeding, cultivation, roads, industry etc)	Y/N
4. Is the drainage faulty allowing ponding within 2m of the well?	Y/N
5. Is the drainage channel cracked, broken or need cleaning?	Y/N
6. Is the fence missing or faulty?	Y/N
7. Is the cement less than 1m in radius around the top of the well?	Y/N
8. Does spilt water collect in the apron area?	Y/N
9. Are there cracks in the cement floor?	Y/N
10. Is the handpump loose at the point of attachment to well head?	Y/N
11. Is the well-cover insanity?	Y/N

Total Score of Risks …./11

Risk score: 9-11 = Very high; 6-8 = High; 3-5 = Medium; 0-3 = Low

III **Results and Recommendations**:
The following important points of risk were noted:
(list nos. 1-11)

Signature of Health Inspector/Assistant:

Comments:

I. **Type of Facility** RAINWATER COLLECTION AND STORAGE

1. General Information : Zone
   : Location
2. Code Number
3. Date of Visit
4. Water sample taken? …….. Sample No. ……… FC/100ml ………..

II Specific Diagnostic Information for Assessment

	Risk
1. Is rainwater collected in an open container?	Y/N
2. Are there visible signs of contamination on the roof catchment? (e.g. plants, excreta, dust)	Y/N
3. Is guttering that collects water dirty or blocked?	Y/N
4. Are the top or walls of the tank cracked or damaged?	Y/N
5. Is water collected directly from the tank (no tap on the tank)?	Y/N
6. Is there a bucket in use and is this left where it can become contaminated?	Y/N
7. Is the tap leaking or damaged?	Y/N
8. Is the concrete floor under the tap defective or dirty?	Y/N
9. Is there any source of pollution around the tank or water collection area?	Y/N
10. Is the tank clean inside?	Y/N

Total Score of Risks …./10

Risk score: 9-10 = Very high; 6-8 = High; 3-5 = Medium; 0-3 = Low

III Results and Recommendations:

The following important points of risk were noted:
(list nos. 1-10)

Signature of Health Inspector/Assistant:

Comments: