4. WATER SAFETY PLANS

Detection of microbial and chemical constituents in both raw water and drinking-water is often slow, complex and costly. It has very limited capacity to give early warning of problems with the quality and safety of drinking-water supplied. Generally, monitoring of the quality of the water supplied to the consumer can only verify that the water was safe (or unsafe) after it was supplied. Finally, results of water quality testing relate only to the quality of a non-statistically representative small sampling which is a very small fraction of the whole, whilst water quality may vary widely and rapidly, depending on the constituent of interest .

The most effective and protective means of consistently assuring drinking-water quality and the protection of pubic health is through the application of a preventive Water Safety Plan (WSP) that encompasses all steps in water protection from catchment to the consumer.

The role of the supplier in ensuring the safety of water safety has three key components, which are guided by health-based targets (see Chapter 3) and overseen through public health surveillance (see chapter 5):

1. System assessment to determine whether the water supply chain (up to the point of consumption) as a whole can deliver water of a quality that meets identified targets. This also includes the assessment of design criteria of new systems;
2. Monitoring of the control measures in the supply chain which are of particular importance in securing water safety;
3. Management plans documenting the system assessment and monitoring; and describing actions to be taken during normal operation or incident conditions, including upgrade and improvement, and documentation and communication;

The primary objectives of a WSP in ensuring good drinking-water supply practice, are the prevention of contamination of source waters, the reduction or removal of contamination through treatment processes to meet the water quality targets; and the prevention of contamination during storage, distribution and handling of drinking-water. These objective are equally applicable to utility, community and households and are achieved through:

- Development of a understanding of the specific system and its capability to supply water that meets water quality targets;
- Identification of potential sources of contamination, and how they can be controlled;
- Validation of control measures employed to control hazards;
- Implementing a system for monitoring the control measures within the water system and initiating timely corrective actions to ensure that safe water is consistently supplied; and
- Undertaking verification of water quality to ensure that the WSP is being implemented correctly and is achieving the performance required to meet relevant national water quality objectives.

Validation of processes involves establishing the scientific basis to show that existing or new processes will achieve the required level of performance and to develop the operational criteria required to ensure that hazards are being effectively controlled.

Verification of drinking-water quality provides an assessment of the overall performance of the system and the ultimate quality of drinking-water being supplied to consumers. This incorporates monitoring drinking-water quality as well as assessment of consumer satisfaction.

Management of existing water supply systems or the planning for new systems includes activities at different levels of society, from government to individual consumers. These activities include allocation of the best available water resources to drinking-water supply catchment area, source protection, design of treatment and distribution systems to meet water quality targets and promotion of hygienic use of drinking-water in the domestic environment.

It will often be necessary to balance competing risks and potential health benefit interventions: quality vs. quantity, investment in drinking water vs. wastewater disposal, the relative burden of different hazards that may be associated with different choices for raw water sources, treatment options etc. The role of the public authorities implies flexibility in directing the best use of available resources for overall protection and improvement of public health.

Where a defined entity is responsible for water supply their responsibility should include the preparation and implementation of a water safety plan. This plan should be reviewed and agreed upon with the authority responsible for protection of public health.

Where there is no formal service provider then the competent national or regional authority should act as a source of information and guidance on the adequacy of appropriate approaches to community and individual water supply and for these will define key requirements for monitoring and management. Approaches to verification will depend on the capacity of local authorities and communities and should be defined in national policy. As such systems are especially of concern to public health, empowering local institutions is of great importance.

4.1 ASSESSMENT AND DESIGN

Effective management of the water system requires a comprehensive understanding of the system, the range and magnitude of hazards that may be present, and the ability of existing processes and infrastructure to manage potential risks. Similarly, when a new system or an upgrade of an existing system is being planned, the first step in developing a WSP is the collection and evaluation of all available data for the entire system from catchment to consumer including elements outside the direct control of the supplier (e.g. potentially polluting activities in the catchment) and to undertake an assessment on capabilities to meet targets.

Effective risk management requires the identification of potential hazards, their sources and of hazardous events; and an assessment of the level of risk presented by each. In this context:

- a **hazard** is a 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); and
- **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.

Assessment of the drinking-water supply system is an essential prerequisite for WSP subsequent steps in which effective strategies for prevention and control of hazards are planned and implemented. This includes understanding the characteristics of the drinking-water system, what hazards may arise and from which sources, how these hazards create risks and which hazards, and the processes and practices that affect drinking-water quality.

Information concerning the effectiveness of processes combined with data on the occurrence of pathogens and chemicals in source waters and health-based targets enables definition of catchment management measures and treatment/distribution systems operating conditions that would reasonably be expected to achieve those health targets.

Often, it may be more efficient to invest in preventive processes within the catchment, rather than major capital expenditure on treatment infrastructure to manage a potential hazard.

To optimise activities directed towards the improvement of water quality, it is essential that all elements of the water system (resource and source protection, treatment and distribution) are considered concurrently to ensure that interactions and influences between each element and their overall effect is taken into consideration.

4.1.1 Collecting available data

Effective management of water quality requires an understanding of the water supply system from catchment to consumer. Each element of the water supply system should be characterised with respect to water quality and the factors that affect it. This characterisation assists identification of hazards and magnitude of risks to water quality. In most cases, consultation between public health and other sectors, including polluters, and all those who regulate activities in the catchment will be required for the analysis of catchments. This should include the potential impacts of land uses on water quality and stream and river flows. Individuals involved in each stage of the supply of drinking-water, including catchment managers, bulk suppliers, water managers, operational staff and contractors and community based entities should contribute to the assessment of the drinking-water system.

The overall assessment of the drinking-water system should take into consideration any historical water quality data that assist in understanding source water characteristics and system performance both over time and following specific events (e.g. heavy rainfall).

The assessment and evaluation of the system is enhanced through the development of a flow diagram. Diagrams provide an overview description of the supply, including characterization of the source, identifying potential pollution sources in the catchment, measures for resource and source protection, treatment processes, storage and distribution infrastructure. It is essential that the representation of the system is conceptually accurate. If the flow diagram is not correct, it is possible to overlook potential hazards that may be significant. To ensure accuracy, the flow diagram should be validated by visually checking the diagram with features observed on the ground.

When drinking-water supply sources are being investigated or developed it is prudent to undertake a wide range of analyses in order to establish overall safety and to determine potential sources of in particular microbial, contamination of the source. It would normally include hydrological analysis, geological assessment and landuse inventories to determine other potential chemical and radiological contaminants.

It is essential that all water-quality factors are taken into account when technologies for abstraction and treatment of new resources are selected. Variations in the turbidity and other parameters of raw surface waters can be very great, and allowance must be made for this; treatment plants should be designed for worst-case conditions rather than for average water quality, otherwise filters may rapidly become blocked or sedimentation tanks overloaded. The chemical aggressiveness of some groundwaters may affect the integrity of borehole casings and pumps, leading to unacceptably high levels of iron in the supply, eventual breakdown, and expensive repair work. Both the quality and availability of water may be reduced and public health endangered.

Table 4.1 provides examples of areas that should be taken into consideration as part of the assessment of the drinking-water system. A structured approach is important to ensure that significant issues are not overlooked and that areas of greatest risk are identified.

Table 4.1 Examples of information to compile in assessment of a drinking-water system

Catchments	Geology and hydrology Meteorology and weather patterns General catchment and river health Wildlife (e.g. native and feral animals) 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 transport
Groundwater systems	Confined or unconfined aquifer Aquifer hydrogeology Flow rate and direction Dilution characteristics Recharge area Well-head protection Depth of casing Bulk transport
Treatment systems	Treatment processes (including optional processes) Equipment design Monitoring equipment and automation Water treatment chemicals used Treatment efficiencies Disinfection log removals of pathogens Disinfection residual / contact period time
Service reservoirs and distribution systems	Reservoir design Retention times Seasonal variations Protection (eg covers, enclosures, access) Distribution system design Hydraulic conditions (eg retention times, flows) Backflow protection Disinfectant residuals Disinfection byproducts

4.1.2 Evaluating available data

The types of control measures employed will be different for each water supply and will generally be influenced by characteristics of the source water and surrounding catchment. Selection of new and evaluation of the adequacy of existing control measures is informed by hazard identification and risk assessment alongside prevailing health-based targets.

Hazard identification

Hazards may occur or be introduced throughout the water system from catchment to consumer.

System Risk Assessment

Effective risk management therefore requires identification of all potential hazards, their sources and hazardous events, and an assessment of the risk presented by each.

Once potential hazards and their sources have been identified, the level of risk associated with each hazard/hazardous event should be estimated so that priorities for risk management can be established and documented. Although there are numerous contaminants that can compromise drinking-water quality, not every potential hazard will require the same degree of attention.

Identification and implementation of control measures requires consideration of the multiple barrier principle. The strength of this approach is that a failure of one barrier may be compensated by effective operation of the remaining barriers, thus minimising the likelihood of contaminants passing through the entire system and being present in sufficient amounts to cause harm to consumers. Many control measures may contribute to control more than one hazard, while, some hazards may require more than one control measure for effective control. Examples of control measures are provided in table 4.5, 4.7 4.9 and 4.10.

A structured approach is important to ensure that significant issues are not overlooked and that areas of greatest risk are identified. The risk assessment of the water supply system, it is essential that the individual elements are not considered in isolation.

Prioritising hazards for control

The level of risk for each hazard/hazardous event can be estimated by identifying the likelihood of occurrence (e.g. certain, possible, rare) and evaluating the severity of consequences if the hazard occurred (e.g. insignificant, major, catastrophic). The aim should be to distinguish between very high and low risks

Simple risk ranking matrices typically apply technical information from guidelines, scientific literature and industry practice with well informed "expert" judgement supported by peer review or benchmarking. An important consideration is that the risk ranking is specific for each water supply system since each system is unique.

By using a semi-quantitative risk ranking, a priority score may be calculated for each identified hazard. The objective is to rank control measures to provide a focus on the most significant hazards. A variety of approaches to ranking risk can be applied. An example of an approach is given in Table 4.2.

Table 4.2 - Example of a simple risk scoring table for prioritising risks.
(The risk score for a particular hazardous events = Likelihood x Severity of Consequences.)

	Severity of Consequences				
Likelihood	Insignificant	Minor	Moderate	Major	Catastrophic
Almost Certain	5	10	15	20	25
Likely	4	8	12	16	20
Moderate	3	6	9	12	15
Unlikely	2	4	6	8	10
Rare	1	2	3	4	5

The likelihood and severity can be derived from technical knowledge and expertise, historical data and relevant guidelines. An example of descriptors that can be used to rate the likelihood and severity for calculation of the Risk Score is given in Table 4.3. A 'cut off' point must be determined, above which all hazards will require immediate attention. There is little value in expending further effort considering very small risks.

Control Measures

The assessment and planning of control measures should be based on system-specific hazard identification and risk assessment. The level of protection applied to control a hazard should be proportional to the associated risk. Assessment of control measures involves:

- identifying existing control measures from catchment to consumer for each significant hazard or hazardous event;
- evaluating whether the control measures, when considered together, are effective in reducing risk to acceptable levels; and
- if improvement is required, evaluating alternative and additional control measures that could be applied.

All control measures are important and should be afforded ongoing attention. However, control measures that can significantly prevent or reduce hazards should normally be subject to operational monitoring and control (see Section 4.2.2).

Table 4.3 - Examples of definitions of likelihood and severity categories that can be used in risk scoring.

Item:	Definition:	Weighting:
Almost certain	Once a day	5
Likely	Once per week	4
Moderate	Once per month	3
Unlikely	Once per year	2
Rare	Once every 5 years	1
Catastrophic	Potentially lethal to large population	5
Major	Potentially lethal to small population	4
Moderate	Potentially harmful to large population	3
Minor	Potentially harmful to small population	2
Insignificant	No impact or not detectable	1

(For further information - see Hazard Characterisation)

4.1.3 Resource and source protection

Effective catchment management has additional benefits. By decreasing contamination of source water, the amount of treatment and quantity of chemicals needed is reduced. This may lead to health benefits through reducing the production of treatment byproducts, and economic benefits, through minimising operational costs.

Hazard identification

Understanding variations in raw water quality is important as it impacts requirements for treatment, treatment efficiency and the resulting health risk associated with the finished water. In general, raw water quality is influenced by both natural and human-use factors. Important natural factors include wildlife, climate, topography, geology and vegetation. Human-use factors include point sources (e.g., municipal wastewater and industrial wastewater discharges) and non-point sources (e.g., urban and agricultural runoff including agrochemicals, livestock or recreational use). For examples, discharges of municipal wastewater can be a major source of microbial pathogens; urban runoff and livestock can contribute substantial microbial load, body-contact recreation can be a source of faecal contamination and agricultural run-off can lead to increased challenges to treatment.

Whether water is drawn from surface underground sources, it is important that the characteristics of the local catchment or aquifer are understood, and that the scenarios that could lead to water pollution are identified and managed. The extent to which potentially polluting activities in the catchment can be reduced may appear to be limited by competition for water and pressure for increased development in the catchment. However, introducing good practice in containment of hazardous agents is often possible without substantially restricting activities, and the development of collaboration between stakeholders may be a powerful tool to reduce pollution without reducing beneficial development.

Resource and source protection provide the first barriers in protection of water quality. Where catchment management is beyond the jurisdiction of drinking-water suppliers, the planning and implementation of control measures will require coordination with agencies such as planning authorities, catchment boards, environmental and water resources regulators, road authorities and emergency services. It may not be possible to apply all aspects of resource and source protection initially, nevertheless, priority should be given to catchment management including development of a sense of ownership and joint responsibility for drinking-water resources through multi-stakeholder bodies which assess pollution risks from catchments and develop plans for improving management practices for the activities causing these risk as well as for water management.

Groundwater from depth is often microbially safe and chemically stable; however, shallow or unconfined aquifers can be subject to contamination from discharges or seepages associated with agricultural practices (e.g. pathogens, nitrates and pesticides), septic tank discharges (pathogens and nitrates) and industrial wastes. Control measures for groundwater sources should include protecting the aquifer and the local area around the borehead from contamination and ensuring the physical integrity of the bore (surface sealed, casing intact etc). Potential hazards that can impact on resource and source water that should be taken into consideration as part of a hazard assessment are provided in table 4.4.

Table 4.4 Examples for hazardous situations potentially associated with resource and source water

Catchments	• Geology • Rapid variations in raw water quality • Sewage and septic system discharges • Industrial discharges • Chemical use in catchment areas (e.g. use of fertilisers and agricultural pesticides) • Major spills / accidental spillage • Public roads • Human access (recreational activity) • Wildlife (native and feral) • Unrestricted livestock • Inadequate buffer zones • Surrounding land use (e.g. animal husbandry, agriculture, forestry, industrial area, waste disposal, mining) • Changes in surrounding land use • Poorly vegetated riparian zones and failure of sediment traps / soil erosion • Stormwater flows and discharges • Existing or historical waste-disposal or mining sites / contaminated sites / hazardous wastes • Unconfined and shallow aquifer • Groundwater under direct influence of surface water • Inadequate well-head protection and unhygienic practices • Uncased or inadequately cased bores • Saline intrusion of coastal aquifers • Contaminated aquifer • Climatic and seasonal variations (e.g. heavy rainfalls, droughts) • Bush fires, natural disasters, sabotage
Storage reservoirs and intakes	• Human access / absence of exclusion areas around points of abstraction • Short-circuiting of reservoir • Depletion of reservoir storage • No selective withdrawal • No alternative water sources • Unsuitable intake location • Cyanobacterial blooms • Stratification • Soil erosion • Inadequate buffer zones and vegetation • Climatic and seasonal variations (e.g. heavy rainfalls, droughts) • Public roads / accidental spillage • Failure of alarms and monitoring equipment • Bush fires and natural disasters • Sabotage

Control measures

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 the protection of water resources from potentially polluting activities and are enforced; and
- promoting awareness in the community of the impact of human activity on water quality.

Retention of water in reservoirs can reduce the number of faecal microorganisms through settling and inactivation, including solar (ultraviolet) disinfection. Most pathogenic microorganisms of faecal origin (enteric pathogens) do not survive indefinitely in the environment. Substantial die-off of enteric bacteria will occur over weeks. Enteric viruses and protozoa will often survive for longer periods (weeks to months) but are often removed by settling. Retention also allows suspended material to settle, which makes subsequent disinfection more effective and reduces the formation of disinfection byproducts.

Where a number of water sources are available, there may be flexibility in the selection of water for treatment and supply. It may be possible to avoid taking water from rivers and streams when water quality is poor (eg following heavy rainfall) in order to reduce risk and prevent potential problems in subsequent treatment processes.

Table 4.5 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 • Control of human activities within catchment boundaries • Control of wastewater effluents • Land use planning procedures • Regular inspections of catchment areas • Diversion of local stormwater flows • Protection of waterways • Runoff interception • Use of planning and environmental regulations to regulate potential water polluting developments • Maintaining security to prevent sabotage and illegal tampering
Water extraction and storage systems	• Use of available water storage during 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 • Prevention of unauthorised access • Roofed storages and reservoirs with appropriate stormwater collection and drainage • Securing tanks from access by animals • Maintaining security to prevent sabotage and illegal tapping and tampering

For further information on use of indicators in catchment characterisation is available in Chapter 4, OECD Indicators document

4.1.4 Treatment

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

Hazard identification

Hazards associated with treatment of drinking-water are those undesirable constituents introduced, either naturally or from man-made sources into source water. Other constituents of drinking-water can be introduced through the treatment process, including chemical additives used in the treatment processes, or from products in contact with drinking-water. Sporadic occurrences of source water of high turbidity that overwhelm the treatment train, or microorganism breakthrough for example resulting from sub-optimal filtration following filter backwashing, can introduce enteric pathogens into the distribution system.

Potential hazards that can impact on the performance of the drinking-water treatment are listed in table 4.6.

Table 4.6 – Hazards associated with treatment of drinking-water

Treatment systems	• Significant flow variations through water treatment system • Inadequate equipment/ unit processes • Inadequate backup • Inappropriate treatment processes • Process control incapability / operational flexibility • Use of unapproved or contaminated water treatment chemicals and materials • Chemical dosing failures • Inadequate mixing • Failure of dosing equipment • Inadequate filter operation and backwash recycling • Ineffective disinfection • Equipment malfunctions • Poor reliability of processes • Failure of alarms and monitoring equipment • Power failures • Sabotage and natural disasters • Formation of disinfection byproducts

Control measures

Pretreatment can broadly be defined as any process to modify water quality prior to the treatment plant, and 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 process.

Coagulation, flocculation, sedimentation (or flotation) and filtration remove particles, including microorganisms (bacteria, viruses and protozoa). It is important that operations 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 induces any new microbial hazard to finished water, a failure or inefficiency in the coagulation process could result in a high microbial risk to drinking-water consumers.

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. Granular media filtration may in some cases be the only 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 processes to achieve the necessary level of microbial risk reduction. Estimation of the level of microbial inactivation through the application of the CT concept (disinfectant concentration and contact time) for a particular pH and temperature for the more resistant microbial pathogens ensures that other more sensitive microbes are also effectively controlled. In some cases application of the CT concept can be as simple as providing a certain disinfectant residual for a prescribed contact time.

The most commonly used disinfection processes are primary chlorination and chloramination (for maintaining residual), but ozone, ultraviolet irradiation 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 very effective in inactivating *Cryptosporidium;* 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 microorganisms such as *Giardia* and some viruses.

4.1.5 Piped Distribution Systems

Providing a disinfectant residual throughout the distribution system can provide protection against recontamination and limit regrowth problems. Where a disinfectant residual is used within a distribution system minimisation of the production of disinfection byproducts needs to be taken into considered. Chloramination has proved successful in controlling *Naegleria fowleri* in water and sediments in long pipelines.

Water treatment can be optimised to prevent microbial aftergrowth, corrosion of pipe materials and the formation of deposits through:

- continuous and reliable elimination of particles and the production of water of low turbidity;
- precipitation and removal of dissolved (and particulate) iron and manganese;
- minimising the carry-over of residual coagulant (either dissolved, colloidal or particulate) which may precipitate in reservoirs and pipework;
- reducing as far as possible the dissolved organic matter and especially easily biodegradable organic carbon which correspond to the carbon-based nutrients for micro-organisms; and
- maintaining the corrosion potential within limits that avoid damage to the structural materials and consumption of disinfectant.

Table 4.7 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 • Use of skilled and trained operators • 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

For further information in available in *Impact of treatment on microbial water quality: a review document on treatment efficiency to remove pathogens* (LeChevallier and Au, 2002).

Hazard identification
The quality of water can change within the distribution system following treatment and can be influenced by a number of hazards (see table 4.8). Maintaining good water quality in the distribution system will depend on the operation and design of the system, and maintenance and survey procedures to prevent contamination and to remove and prevent accumulation of internal deposits.

The protection of the distribution system is one of the most important control measures for providing safe drinking-water. Microbial contamination has a greater probability of resulting in public health risk by by-passing even effective application of the previous control steps. Because of the nature of the distribution system, with many miles of pipe, storage tanks, interconnections with industrial users, and the potential for tampering and vandalism, opportunities for contamination exist. Control measures should focus on three essential elements: maintaining the quality of the treated water by adequate distribution system maintenance procedures, minimizing bacterial regrowth, and preventing recontamination of the water during distribution.

Drinking-water entering the distribution system may contain free-living amoebae and environmental strains of various bacterial species, often referred to as heterotrophic bacteria. Under favourable conditions amoebae and heterotrophs will colonise a distribution system and form biofilms. Many environmental strains of bacteria such as *Citrobacter*, *Enterobacter* and *Klebsiella* may also colonise distribution systems. There is no evidence at present to implicate the occurrence of these microorganisms from biofilms (excepting for example, *Legionella* or *Mycobacterium*) with adverse health effects in the general population with the possible exception of immuno-compromised population groups.

Water temperatures and nutrient concentrations are not generally elevated enough within the distribution system to support the growth of *E. coli* (or enteric pathogenic bacteria) in biofilms. Thus the presence of *E. coli* should be considered as evidence of recent faecal contamination.

Chemical hazards may be introduced from materials such as pipes, solders/jointing compounds, taps and chemicals used in cleaning and disinfection of distribution systems.

Contamination can occur within the distribution system, through:

- *Infiltration*. Contaminated sub-surface water is drawn into the distribution system, when contaminated water in the sub-surface material surrounding the distribution system, enters a low-pressure zone or through the effect of a “pressure wave” within the system.
- *Back siphonage*. Faecally contaminated water is drawn into the distribution system or storage reservoir through a back flow mechanism resulting from a reduction in line pressure and a physical link between contaminated water and the storage or distribution system.
- *Open drinking-water storage reservoirs*. Microbial contamination can also be introduced into the distribution system through open treated-water storage reservoirs.

- *Line construction and repair*. When existing mains are repaired or replaced or when new water mains are installed strict protocols involving disinfection and flushing must be followed to prevent the introduction of contaminated soil or debris into the system.
- *Cross-connection.* Human error resulting in the unintentional cross-connection of waste-water or storm water pipes to the distribution system, or through illegal or unauthorised connections.
- By dissolution from unsafe materials (distribution and plumbing pipes, taps etc.).

In each case, if the contaminated water contains enteric pathogens or hazardous chemicals then it is likely that consumers will be exposed to them. Even where disinfectant residuals are employed to limit microbial occurrence it may be inadequate to overcome the contamination or may be ineffective against some or all of the pathogen types introduced. As a result, pathogens may occur in concentrations that could lead to infection and illness. In situations where water is supplied intermittently, the resulting low water pressure will allow the ingress of contaminated water into the system through breaks, cracks, joints and pinholes in the walls of the system.

Intermittent systems are very common in many countries and are frequently associated with contamination. Although intermittent systems are not desirable, they are the reality for a large proportion of the World's population. The control of water quality in intermittent supplies represents a significant challenge to water suppliers, as the risk of infiltration and back-siphonage significantly increases. The risk may be elevated seasonally as soil moisture conditions increase the likelihood of a pressure gradient developing from the soil to the pipe.

Where contaminants enter the pipes in an intermittent supply, the charging of the system when supply is restored may increase risks to consumers as a concentrated 'slug' of contaminated water can be expected to flow through the system. Where on-site storage is used to overcome intermittent supply, use of disinfectants to reduce microbial proliferation may be warranted

Table 4.8 Potential sources of contamination and hazardous events – distribution systems

Service reservoirs and distribution systems	
• Open reservoirs and aqueducts/ uncovered storages and unprotected pipe system	• Biofilms, sloughing and resuspension / regrowth
• Human access	• Pipe bursts / leaks
• Animal access including bird and vermin	• Inadequate repair and maintenance / inadequate system flushing and reservoir cleaning
• Areas of high density populations	• Commissioning new mains
• Cross-connections and proximity to sewers	• Inadequate disinfection after construction, repairs
• Short-circuiting of reservoir / stagnation zones	• Flow variability / inadequate pressures
• Build up of sediments and slimes	• Treatment dosing failure
• Inappropriate materials and coatings or material failure	• Inadequate maintenance of chlorine residual
• Aged pipes, infrastructure	• Formation of disinfection byproducts
• Corrosion of reservoirs and pipe system	• Failure of alarms and monitoring equipment
• Mixing of different source waters	• Sabotage and natural disasters
• Infiltration and ingress of contamination from cross connections, backflow (soil and groundwater)	• Illegal connection

Control measures

Water entering the distribution system must be microbiologically safe and ideally should be biologically stable. The distribution system itself must provide a secure barrier to post-treatment contamination as the water is transported to the user. Residual disinfection will provide partial protection against recontamination, but may also mask the presence of such contamination.

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 throughout the distribution system. Appropriate security needs to be put in place to prevent unauthorised access and/or interference with water storages.

Control measures include using a more stable secondary disinfecting chemical (such as chloramines instead of free chlorine), making operational changes to reduce the time that water spends in the system (avoid stagnation in storage tanks and looping dead-end sections), undertaking a program of pipe replacement, flushing and relining, and maintaining positive pressures in the distribution system.

The measure most often used to determine if a distribution system has delivered water of an acceptable quality is the presence or absence of microbial indicator bacteria. However, there are pathogens that are more resistant to chlorine disinfection than the more commonly thermotolerant coliforms and/or *E. coli* and enterocci including organisms such as Clostridium *perfringens* spores' coliphages.

Table 4.9	**Examples of distribution 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 and illegal tapping and tampering

For further information in available in Microbial quality in piped distribution systems.; a review of knowledge and practices.

4.1.5 Non-piped, community and household systems

In contrast to utility piped supplies, the development of a WSP (including hazard identification and defining preventative measures) for community-managed water supplies will be most effectively achieved through the development materials that are specific to technologies rather than individual supplies.

The large number of community-managed water supplies in many countries makes development of individual/customized water safety plans for each individual supply unfeasible. As the majority of the issues will be common, technology-specific approaches will be appropriate. Training is required for community operators to ensure that the water safety plan is applied and followed.

Hazard identification

Hazard identification would ideally be on a case-by-case basis but in practice for non-piped, community and household systems, reliance is typically placed on general assumptions of hazardous conditions relevant at national or regional level. Further guidance is provided in ‘Water Safety Plans’ and in Guidelines for Drinking-water Quality Volume 3.

Control measures

The types of control measures required will depend on the characteristics of the source water and the associated catchment; in practice standard approaches may be applied for each of these rather than customized assessment of each system.

In most cases, contamination of groundwater supplies can be prevented by a combination of simple measures. Groundwater in confined or deep aquifers will generally be free of pathogenic microorganisms and, providing the water is protected during transport from the aquifer to consumers, microbiological quality should be assured. Bores should be encased to a reasonable depth and boreheads should be sealed to prevent ingress of surface water or shallow groundwater.

Once the groundwater is pumped out of the aquifer, protection can be achieved by delivering the water through enclosed water systems. Storage tanks should be roofed, pipelines should be intact and cross-connections should be protected by the installation of backflow prevention devices.

Rainwater systems, particularly those involving storage in above-ground tanks, should be a relatively safe supply of water. The principal sources of contamination are birds, small animals and debris collected on roofs. The impact of these sources can be minimised by a few simple measure: guttering should be cleared regularly; overhanging branches should be kept to a minimum because they can be a source of debris and can increase access to roof catchment areas by birds and small animals; and inlet pipes to tanks should include leaf litter strainers. First flush diverters, which prevent the initial roof cleaning wash of water (20–25 L) from entering tanks, are recommended. If first flush diverters are not available, a detachable downpipe can be used to provide the same result.

Assurance of quality from surface water sources is more difficult than from most groundwater or rainwater systems. In general, surface waters will require at least disinfection, and often filtration, to assure microbiological safety. However, as for groundwater systems, the first barrier is to prevent contamination at source by minimising contamination from human waste, livestock and other hazards as discussed above. The greater the degree of protection of the water source the lesser the reliance on treatment/disinfection. After treatment or disinfection, water should be protected during storage and delivery to consumers in the same manner as groundwater, by ensuring that distribution and storage systems are enclosed.

For control of chemical hazards reliance may be placed primarily on initial screening of sources and on ensuring the quality and performance of chemicals, materials and devices available for this use.

4.1.7 Process validation

Validation is concerned with obtaining evidence that the elements of the Water Safety Plan will be effective. 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 - that the water supplier is 'going to do the right things' - thus enabling conformity with health-based targets. Evidence to support the Water Safety Plans can come from a variety of sources.

Process validation is required to show that treatment processes can operate as required. It can be undertaken during pilot stage studies and is a useful tool in the optimisation of existing treatment processes.

The first stage of validation is to consider data that already exists. This will inform the testing requirements, including specific pathogens or indicator. This will include the scientific literature, trade associations, regulation and legislation departments, historical data, professional bodies, or supplier knowledge.

Process validation is not a tool that is used for day-to-day management of drinking-water supplies, but in the design of systems including treatment processes. Microbial parameters such as heterotrophic plate count and coliforms which may be inappropriate for operational monitoring can be used. The lag time for return of results and additional costs from pathogen measurements can be tolerated in process validation as this monitoring is not used to support the day-to-day management of water safety.

4.2 MONITORING

4.2.1 Operational monitoring

Control measures are any activity that reduce levels of hazards within water either by preventing entry, reducing concentration or by restricting proliferation. They are identified by considering the events that can cause contamination of water, both directly and indirectly, and the activities that can mitigate the risks from those events. Control measure exist in source, treatment and distribution.

The key element for operational monitoring is for water suppliers to undertake a timely assessment of the performance of the system to determine whether each control measure identified ? system assessment as essential to achieve health-based targets is functioning properly. The aim of operational monitoring is to support management of the operation of the system and ensure that control measures are working effectively. Microbial parameters, such as indicator bacteria are of limited use for operational monitoring because the time taken to process and analyse water samples prohibits operational adjustments to be made if the process is not within set criteria.

The parameters selected for operational monitoring should reflect the operational effectiveness of each control measure, provide an immediate indication of performance and be able to be readily measured and provide opportunity for rapid response.

Some water quality characteristics can serve as surrogates (indicators) for characteristics for which testing is more difficult or expensive. For example, conductivity is a widely used surrogate for total dissolved solids (TDS). Similarly, trihalomethanes (THMs), which are the most common disinfection byproducts and occur at among the highest concentrations, serve as a surrogate for a range of related byproducts.

Non-microbial parameters may also be suitable for assessment of changes and trends of water quality in distribution networks. The most frequently used examples include conductivity/total dissolved solids, turbidity and chlorine residual (where chlorine is applied). Where chlorine residuals are used, measurement of this residual will generally provide a more rapid indication of problems than microbial parameters. A sudden disappearance of an otherwise stable residual can indicate ingress of contamination. Alternatively, difficulties in maintaining residuals at points in a distribution system or a gradual disappearance of residual may indicate that the water or pipe work has a high oxidant demand due to re-growth of bacteria in the water or biofilm growth.

Most control measures have defined limits for operational acceptability that can be monitored, directly or indirectly through surrogates. If monitoring shows that a process operating limit has been exceeded, then there is the potential for water to be, or to become, unsafe. Process operating limits might be set for the system to run at optimal performance whilst critical limits might be set when corrective actions are required to prevent or limit the impact of potential hazards on the safety and quality of the water. Such events should result in immediate notification of the appropriate health regulator. Control measures are also treated with pre-determined corrective actions to be applied when deviations are detected by monitoring. The process of detection of the deviation and implementation of corrective action(s) should be possible in a timeframe adequate to maintain water safety.

The objective is to monitor control measures to in a timely manner to prevent the supply of any potentially unsafe water. A record of monitoring should be maintained. Monitoring programs should be reviewed periodically, and altered where necessary.

4.2.2 Determine system control measures

The identity and number of control measures is system specific and will be determined by the range and magnitude of potential hazards and associated risks. Control measures have a number of operational requirements, including:

- operational parameters that can be measured and for which limits can be set to define the operational effectiveness of the activity (e.g. chlorine residuals for disinfection);
- operational parameters that can be monitored with sufficient frequency to reveal any failures in a timely fashion; and
- procedures for corrective action that can be implemented in response to deviation from limits.

In any system, there may be very many hazards and potentially large number of control measures. Control measures identified should reflect the likelihood and consequences of loss of control. It may therefore be important to establish priorities for control measures.

Generally the measurement of critical limits needs to be rapid enough so that there can be a prompt response to any significant deviations. Examples of critical limits are minimum and maximum chlorine residuals or minimum and maximum hydraulic pressures at strategic locations in the distribution system.

Table 4.10 Examples of treatment control measures

	Treatment step/process					
Operational parameter	***Raw water***	***Coagulation***	***Sedimentation***	***Filtration***	***Disinfection***	***Distribution system***
PH		✓	✓		✓	✓
Turbidity (or particle count)	✓	✓	✓	✓	✓	✓
Dissolved oxygen	✓					
Stream/river flow	✓					
Rainfall	✓					
E. coli	✓				✓	✓
Heterotrophic bacterial count					✓	✓
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 byproducts					✓	✓
Hydraulic pressure						✓

Ct = Contact time

4.2.3 Establish operational and critical limits

Process operating limits should be defined for each control measure, which, if not in compliance, will compromise the ability of the supply to meet identified targets. Examples of criteria that are used as operational or critical limits include measurable variables, such as chlorine residuals, pH and turbidity, or observable factors, such as observing the integrity of vermin-proofing screens. The limits need to be directly or indirectly measurable.

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

4.2.4 Operational monitoring for drinking-water quality

A range of measures can be considered as part of a monitoring programme for source waters. These include monitoring source water for turbidity, UV absorbency, algal growth, flow including retention time, colour, conductivity and local meteorological events.

Treatment
It is important that a monitoring protocol is developed that is appropriate for the system employed. Parameters that should be considered as part of a monitoring protocol may include disinfection contact time (CT), UV intensity (IT), pH, light absorbency, membrane integrity, turbidity, colour.

Piped distribution
Operational monitoring within the distribution system may include monitoring chlorine dose for primary and relay disinfection, chlorine residual monitoring, pressure measurement and turbidity.

Measuring the numbers of heterotrophic bacteria present in a supply can be a useful indicator of changes such as increased re-growth potential, increased biofilm activity, extended retention times or stagnation and a breakdown of integrity of the system. reflect the presence of large contact surfaces, such as in line filters, and are not direct indicators of the condition of the distribution system.

Comprehensive guidance for management of distribution system operation and maintenance is available (see also *Microbial Water Quality in Piped Distribution Systems: A review of Knowledge and Practice*). This includes a development of a monitoring program for water quality and other parameters such as pressure.

Non-piped distribution systems
Point water sources are those that have been protected or improved and where the user collects water at the source and transports this back to the home. This includes off-site sources (such as boreholes, wells and springs) as well household rainwater collection. Treatment of water in such sources is rarely practiced, but if treatments are applied then routine monitoring of operational parameters is essential.

Monitoring of water sources (including rainwater tanks) by community operators or households will typically involve sanitary inspection plus visual inspection of water appearance on a regular basis. The sanitary inspection forms used should be comprehensible and easy to use, for instance the forms may be pictorial. The risk factors included should be directly related to activities under the control of the operator and which may change rapidly. The links to action from the results of operational monitoring should be clear and training will be required.

A shortened inspection form for frequent use may be of more value to the operators than a full sanitary inspection form, which cover other aspects such as proximity of latrines. The surveillance agency should undertake periodic full sanitary inspections to evaluate operational monitoring and to provide guidance to communities where problems are noted.

Operators should also undertake regular visual assessments of the water, especially after heavy rains, to monitor whether any obvious changes in water quality occur (for instance changes in colour, odour, taste or turbidity). It is essential that this is linked to a well-defined procedure for operators to gain support in resolving these.

Collection, transportation and storage of water in the home

Maintaining the quality of water during collection and transport from a water source is the responsibility of the household. Good hygiene practices are required and should be supported through hygiene education.

It is unlikely that hygiene practices alone will be able to prevent all re-contamination and household treatment of water has proved to be effective in delivery of public health gains. Monitoring of treatment processes will be specific to the technology. When household treatment is introduced, it is essential that training is provided to users to ensure that they understand basic operational monitoring requirements.

4.2.5 Verification

Verification provides a final 'catch all' confirmation of the efficacy of the overall safety of the supply chain. It primarily involves the assessment of faecal indicator bacteria and identified chemicals. This may be undertaken by the supplier and/or the surveillance agency.

The frequency of sampling will be determined by the resources available. The more frequently the water is examined, the more likely it is that chance contamination will be detected. There are two main points to be noted. First, the chance of detecting pollution that occurs periodically, rather than randomly, is increased if samples are taken at different times of day and on different days of the week and across seasons. Second, frequent examination by a simple method is more valuable than less frequent examination by a complex test or series of tests. Sampling frequencies for raw water sources will depend upon their overall quality, their size, the likelihood of contamination, and previous analytical results.

Regulatory agencies should establish a minimum sampling frequency requirements for operational monitoring of indicators and generally a limit to the number of positive samples.

Sampling frequencies for treated water leaving the waterworks depend on the quality of the water source and the type of treatment. Minimum frequencies are: one sample every 2 weeks for waterworks with a ground water source; and one sample every week for waterworks with a surface water source.

The frequency of sampling should be greater where the number of people supplied is large, because of the higher number of people at risk. Advice on the design of sampling programmes and on the frequency of sampling is given in ISO standards (Table 4.14) and in national regulations.

Table 4.11 International Organization for Standardization (ISO) standards for water quality giving guidance on sampling

ISO standard no.	Title (water quality)
5667-1:1980	Sampling - Part 1: Guidance on the design of sampling programmes
5667-2:1991	Sampling - Part 2: Guidance on sampling techniques
5667-3:1994	Sampling - Part 3: Guidance on the preservation and handling of samples
5667-4:1987	Sampling - Part 4: Guidance on sampling from lakes, natural and man-made
5667-5:1991	Sampling - Part 5: Guidance on sampling of drinking-water and water used for food and beverage processing
5667-6:1990	Sampling - Part 6: Guidance on sampling of rivers and streams
5667-13:1997	Sampling – Part 13: Guidance on sampling of sludges from sewage and water-treatment works
5667-14:1998	Sampling – Part 14: Guidance on quality assurance of environmental water sampling and handling
5667-16:1998	Sampling – Part 16: Guidance on biotesting of samples
5668-17:2000	Sampling – Part 17: Guidance on sampling of suspended sediments
13530:1997	Water Quality – Guide to analytical control for water analysis

Samples should be spaced randomly within each month and from month to month. Frequency of sampling should be increased at times of epidemics, flooding, emergency operations, or following interruptions of supply or repair work.

With systems serving small communities, periodic sanitary surveys are likely to yield more information than infrequent sampling.

For unpiped supplies and untreated water, the quality and likelihood of contamination will vary seasonally, meteorologically and with local conditions. The frequency should be established by the local control agency and reflect local conditions, including the results of sanitary surveys.

Sampling locations will depend on the water quality characteristic being examined. Sampling at the treatment plant or at the head of the distribution system may be sufficient for characteristics where concentrations do not change during delivery; however, for those that can change during distribution, sampling should be undertaken throughout the distribution system, including the points of supply to the consumer and should be taken both from fixed points, such as pumping stations and tanks, and from random locations throughout the distribution system, including points near its extremities and taps connected directly to the mains in houses and large multi-occupancy buildings, where there is a greater risk of contamination through cross-connections and back-siphonage.

Frequency of testing for individual characteristics will depend on variability. Sampling should be frequent enough to enable the monitoring to provide meaningful information and statistical validity. Sampling and analysis are required most frequently for microbiological constituents, and less often for organic and inorganic compounds. This is because even brief episodes of microbial contamination can lead to immediate illness in consumers, whereas, in the absence of a specific event (eg chemical overdosing at a treatment plant), episodes of chemical contamination that would constitute an acute health concern are rare.

The adopted frequencies of sampling reflect the need to balance the benefits of better information arising from greater frequency with increasing costs (and decreasing returns) as overall frequency increases. Sampling frequencies are usually based on the population served by the network/zone or, less frequently, on the volume of water supplied

Sampling for microbial quality

Strategies for monitoring the microbial quality of water in supply must be designed to allow the best possible chance of detecting reductions in microbial quality. It is vital, therefore, to ensure that the samples taken are representative of the water in the distribution network, or non-piped supply storage systems.

In any faecal contamination event of both pathogenic or indicator microorganisms, whether introduced by inadequate treatment or post-treatment contamination. Microorganisms are not distributed evenly throughout the distribution system but are typically clumped. In these situations the probability of detecting faecal indicator bacteria in the relatively few samples collected from the distribution system during routine sampling is substantially reduced.

Presence absence testing is only appropriate in any system where the majority of tests for indicators provides negative results. Comparative studies of the P/A and MF methods demonstrate that the P/A method can maximise the detection of faecal indicator bacteria. It also allows more samples to be analysed within a reporting period because the test is simpler, faster and less expensive than the quantitative methods.

Sampling for chemical contaminants

Issues that need to be addressed in developing chemical monitoring include the availability of appropriate analytical facilities, the cost of analyses, the possible deterioration of samples, the stability of the contaminant, the likely occurrence of the contaminant in various supplies, the most suitable point for monitoring and the frequency of sampling.

Substances that are stable in concentration and do not change significantly require less frequent sampling than those which might vary significantly. In many cases sampling once per year, or even less, may be quite adequate, particularly in stable groundwaters. Surface waters are likely to be more variable and require a greater number of samples depending on the contaminant and its importance. It is also important to determine the best point for taking samples for monitoring a particular contaminant. In the case of lead for example, sampling is required at the tap rather than the treatment works, since the source of lead is usually service connections or plumbing in buildings. Other contaminants may not change significantly in distribution and monitoring at the treatment works or source will be appropriate.

Consideration also needs to be given to the feasibility of control of a contaminant, whether by treatment or control of inputs, and whether the risks associated with that contaminant warrant inclusion in a monitoring programme. In the event of a contaminant not being amenable to control a decision needs to be taken as to whether the potential risks justify monitoring in order to establish the risks more precisely with a view to taking appropriate action when this is possible.

Sampling community-managed supplies

Periodic testing and sanitary inspection of microbial quality of community supplies should be undertaken by the surveillance agency. Routine sampling is unlikely to be possible and therefore a rolling programme of visits may be established to ensure that each supply is visited once every 3-5 years. The purpose of such sampling is to inform strategic planning and policy rather than assessment of compliance of individual water supplies. Analysis of chemical quality of all sources is recommended prior to commissioning as a minimum and preferably on 3-5 year basis.

4.2.6 Preparing an operational monitoring plan

Monitoring programs should be developed, detailing the strategies and procedures to follow for monitoring the various aspects of the water supply system. The monitoring plans should be fully documented and include the following information:

- parameters to be monitored;
- sampling location and frequency;
- sampling methods and equipment;
- schedules for sampling;
- methods for quality assurance and validation of sampling results;
- requirements for checking and interpreting results;

- responsibilities and necessary qualifications of staff;
- requirements for documentation and management of records, including how monitoring results will be recorded and stored;
- requirements for reporting and communication of results.

4.2 OPERATING PROCEDURES– PIPED DISTRIBUTION SYSTEMS

To ensure safe water, the focus of a water safety plan in piped distribution systems should be on:

1. *assessment* of the water supply (see Section 4.1);
2. programmed *operational monitoring* of the water supply system (see Section 4.2);
3. implementation of systematic water quality management procedures, including *documentation and communication* (see Section 4.3);
4. development of programmes to *upgrade and improve* existing water deliver; and
5. establishment of appropriate *incident response* protocols.

Incident response plans can have a range of alert levels. These can be minor, early warning, necessitating no more than additional investigation, through to emergency. Emergencies are likely to require the resources of organisations beyond the water supply authority, particularly the health authorities.

Incident response plans typically comprise:

- Accountabilities and contact details for key personnel, often including several organisations and individuals.
- Lists of measurable indicators that might trigger incidents along with a scale of alert levels.
- Clear description of the actions required in response to alerts.
- Location and identity of the standard operating procedures and required equipment.
- Location of backup equipment.
- Relevant logistical and technical information.
- Checklists, proformas and quick reference guides.

The plan may need to be followed at very short notice so standby rosters, effective communication systems and up to date training and documentation are required.

4.3.1 Management Procedures – predictable incident “deviations”

Corrective action is taken when the results of monitoring at a control measure indicate a loss of control. For example, the ability to change temporarily to alternative water sources a useful corrective action available but is not always possible. 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 in the event of an operational or critical limit being exceeded, safety of supply can be maintained.

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, monitoring may be preferably on-line and may require instantaneous response. For others, such as control of animal densities in catchments, monitoring may only need to be annual and require a response over a period of months to years.

An "incident" is any situation in which there is reason to suspect that water being supplied for drinking is, or is about to become, unsafe. Incident triggers could include:

- Process indicators:
- Inadequate performance of a sewage treatment plant discharging to source water.
- Inadequate performance of drinking-water treatment plant.
- Notification of chance events:
- Spillage of a hazardous substance into source water.
- Failure of power supply to an essential control measure.
- Extreme rainfall in a catchment.
- Detection of unusually high turbidity (source or treated water).
- Unusual taste, odour or appearance of water.
- Microbial indicator parameters:
- Measurement of unusually high faecal indicator densities (source or treated water).
- Measurement of unusually high pathogen densities (source water).
- Public health indicators:
- Disease outbreak for which water is a suspect vector.

Indicators of potentially unsafe water should yield timely information to enable corrective action to prevent unsafe water being supplied. Alert levels can be set against which to compare observations. Alert levels would typically be just within critical limits of operation, outside of which confidence in water safety would be lost. Pre-determined corrective actions can be implemented once alert levels are exceeded. The corrective action plans form part incident response.

4.3.2 Management Procedures – Emergencies

Water suppliers should develop plans to be invoked in the event of an emergency. These plans should consider potential natural 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 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.

Plans should be developed in consultation with relevant regulatory authorities and other key agencies, and should be consistent with existing national 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 health surveillance.

Staff should be trained in emergency response to ensure that they can manage incidents and/or emergencies effectively. Incident and emergency response plans should be regularly reviewed and practised. This improves preparedness and provides opportunities to improve the effectiveness of plans before an emergency occurs.

Following any incident or emergency, an investigation of the incident or emergency 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 incident/emergency should also be established. The organisation should learn as much as possible from the incident to improve preparedness and planning for future incidents. Review of the incident may indicate necessary amendments to existing protocols.

Most drinking-water supply systems are characterized by long periods of steady state performance, and short periods of "stress". Examples of such stress events are filter backwashing, high turbidity in the raw water caused by rainfall and associated with higher numbers of pathogens in the raw water and less removal and inactivation by treatment, algal blooms in the source water that reduce the effectiveness of physico-chemical treatment, distribution failures by pressure drops or recontamination during household storage. Stresses are not restricted to treatment but also apply to groundwater sources (typically from flooding) and to distribution systems (e.g. low-pressure operation).

In an emergency, a decision to close the supply carries an obligation to provide an alternative safe supply. Advising consumers to boil water, initiating super-chlorination, and undertaking immediate corrective measures may be preferable.

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, the 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 boil the water during the emergency. The water should be brought to a rolling boil regardless of altitude.

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 WHO Guideline Values recommended in these Guidelines 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.

In emergencies, e.g. in refugee camps, during outbreaks of potentially waterborne disease, or when faecal contamination of a water supply is detected, the concentration of free chlorine should be increased to greater than 0.5 mg/litre throughout the system.

4.3.3 Management Procedures – unplanned events

Some scenarios that lead to water being considered potentially unsafe might not be specifically identified within incident plans. This may be either because the events were unforeseen, or because they were considered too unlikely to justify preparing detailed corrective action plans. To allow for such events, a generalised water safety incident response plan can be developed. The plan would be used to provide general guidance on identifying and handling of incidents along with specific guidance on responses that would be applied to many different types of incident.

Rather than alert-level categories being pre-determined, a protocol for situation assessment and declaring incidents would be provided that includes personal accountabilities and categorical selection criteria. The selection criteria may include:

- Time to effect.
- Population affected.
- Nature of the suspected hazard.

Alert levels can vary, as they do for specified incidents, from minor through to full-scale emergencies. The preparation of clear procedures, accountabilities and equipment for the sampling and storing water in the event of an incident can be valuable for follow up epidemiological or other investigations, and the sampling and storage of water from early on during a suspected incident should be part of the response plan.

The success of unspecified incident responses 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 general unspecified incident preparedness programs. 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 incidents.

4.3.4 Water avoidance and boil water orders

An incident preparedness program should include an evaluation of the basis for calling water avoidance and boil water orders. The objective of the order should be taken in the public interest and typically involves a final decision by health authorities.

Where drinking-water contamination is suspected, the public interest is not always best served by making avoidance or disconnection orders. Often, people do not follow advice to boil their water, in part because of confusion over what to do. Furthermore, boil water notices can have negative public health consequences through causing anxiety and scalds. If advice to boil water is issued then the incident team must be convinced of an ongoing risk to health of drinking tap water, which outweighs any risk from the boil water notice itself.

4.3.5 Upgrade and improvement

The assessment of the drinking-water supply system may indicate that existing practices and technologies may not be sufficiently comprehensive to fully address the range of drinking-water quality issues that can arise, or may not be systematically structured in the system. In many instances, all that may be needed is to review, document and formalise these practices and address any areas where improvements are required. The assessment of the system should be used as developed a plan to address identified needs for full implementation through a water safety plan. Improvement of the drinking-water system may encompass a wide range of issues such as:

- capital works
- training
- enhanced operational procedures
- consultation programs
- research and development
- incident protocols
- communication and reporting.

Improvement plans can include short-term (eg one year) or long-term programs. Short-term improvements might include actions such as improvements to community and the development of community awareness programs. Long-term capital works projects could include covering of water storages or enhanced coagulation and filtration.

Improvement plans should include objectives, actions to be taken, accountability, timelines and reporting. They should be communicated throughout the organisation and to the community, regulators and other agencies.

Implementation of improvement plans will often have significant budgetary implications and therefore may require detailed cost–benefit analysis and careful prioritisation in accord with the outcomes of risk assessment. Implementation of plans should be monitored to confirm that improvements have been made and are effective. Control measures often require considerable expenditure, and decisions about water quality improvements cannot be taken in isolation from other aspects of water supply that compete for limited financial resources. Priorities will need to be established and many improvements may need to be phased in over a period of time.

4.3.6 Supporting programs

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. They provide a basis to apply the principles of good process control that underpin WSPs and contribute to a total quality management approach to drinking-water quality. Supporting programmes are outside the control measures identified by the water authority, and are used to supplement actions to improve water quality and safety. Often, supporting measures may not be under the direct control of the water supplier, but require action by another agency or organisation. It is important to establish a collaborative approach between agencies to ensure appropriate supporting measures are adopted.

Codes of good operating and management practice and hygienic working practice are essential elements of supporting programmes. These are often captured within standard operating procedures. They include, but are not limited to:

- Hygienic working practices documented in maintenance SOPs;
- Attention to personnel hygiene;
- Training and competence of personnel involved in water supply;
- Tools for controlling people and their activities, 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 a verification protocols for the use 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 potable water incidents such as mains bursts. For example, equipment may be designated for potable water work and not for sewage work. Similarly, a specific vessel may be designated for the collection of water from a water source but not for excreta collection or food storage.
- Develop training and educational programmes for personnel involved in activities that could influence water safety. Ensure the training is implemented as an induction and regularly updated.

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 mutually improved practice.

Any activities that contribute to protecting water safety should be included in the supporting programmes. As a result, these programmes can be extensive, varied and involve multiple organisations and individuals. Many supporting programmes involve source protection measures and typically cover aspects of land-use control. Some source protection measures are engineered, such as effluent treatment process and stormwater management practices. These again may form part of supporting programmes in situations where drinking-water and wastewater operations are undertaken by different organisations.

4.4 Management plans – community and household water supplies

Small community supplies worldwide are more frequently subjected to more severe contamination tat their urban equivalents, are more likely to operate discontinuously or intermittently, and are more frequently subject to breakdown and failure.

If the performance of a community water-supply system is to be properly evaluated, a number of factors must be considered. Some countries that have developed national strategies for the surveillance and quality control of water-supply systems have adopted *quantitative service indicators* for application at community, regional and national levels.

Together, these five service indicators provide the basis for setting targets for community water supplies. They serve as a quantitative guide to the comparative efficiency of water-supply agencies and provide consumers with an objective measure of the quality of the overall service and thus the degree of public health protection afforded.

The principal risk to human health from drinking-water is the presence of pathogenic microorganisms. Thus, to ensure safe water, the focus in small supplies should be on:

- *assessment* of the water supply (see Section 4.1);
- programmed *operational monitoring* of the water supply system (see Section 4.2);
- implementation of systematic water quality management procedures, including *documentation and communication* (see Section 4.3.1);
- development of programmes to *upgrade and improve* existing water deliver; and
- establishment of appropriate *incidence response* protocols.

For an individual household supply, the emphasis should be on selecting the best quality source water available, and on protecting its quality by the use of barrier systems and maintenance programs. Whatever the source (ground, surface or rainwater tanks), householders should assure themselves that the water is safe to drink. Generally, surface water and some shallow groundwater should receive treatment in order to be useable. Information on the quality of surface and groundwater may be available from state or local governments, which may monitor the particular source water as part of a water monitoring program. Alternatively, an individual household should consider having the water tested for any key health characteristics identified as being of local concern. Where the raw water quality does not meet these Guidelines, a point

4.4.1 Essential parameters of drinking-water quality in community supplies

The principal risks to human health associated with community water supplies are microbial. Traditionally, only relatively few water-quality tests were used to establish the safety of supplies based on the assumption that health authorities would be aware of specific sources of risk in each region, such as chemical contamination. However, it is far more effective to implement a preventive approach to the management of drinking-water quality operating from catchment to tap, which reduces the risk from potential water borne hazards.
The parameters recommended for the minimum monitoring of community supplies are those that best establish the hygienic state of the water and thus the risk (if any) of waterborne infection. The essential parameters of water quality are thus:

- *E. coli*; thermotolerant (faecal) coliforms are accepted as suitable substitutes
- chlorine residual (if chlorination is practised).

These should be supplemented, where appropriate, by:

- pH (if chlorination is practised);
- turbidity (if *any* treatment is effected).

These parameters may be measured *on site* using relatively unsophisticated testing equipment. On-site testing is essential for the determination of turbidity and chlorine residual, which change rapidly during transport and storage; it is also important for the other parameters where laboratory support is lacking or where transportation problems would render conventional sampling and analysis difficult or impossible.

Other health-related parameters of local significance should also be measured. It may sometimes be useful to include *E. coli* in the bacteriological analysis, e.g. if chlorination is practised and there is an extensive distribution network. Generally, surface water or shallow groundwater should not be used as a source of drinking-water without treatment or sanitary protection.

4.5 Documentation and communication

Records are essential for reviewing the adequacy of the WSP and the adherence of the water supply system to the WSP.

Four types of records should be kept:

1. Support documentation for developing the WSP.
2. Records generated by the WSP.
3. Documentation of methods and procedures used.
4. Records of employee training programmes.

Records are kept to demonstrate adherence of the system with the WSP. These records are used to demonstrate effectiveness of control measures in meeting identified targets. By tracking records generated by the WSP system, an operator or manager can become aware that a process is approaching its critical limit. Review of records can be instrumental in identifying trends and in making operational adjustments. Periodical review of WSP records is recommended so trends can be noted and appropriate actions decided upon and implemented.

Communication strategy should include:

- Procedures for promptly advising of any significant incidents to the water supplier as well as the public health protection agency and, in the event of serious transgressions, consumers;
- Summary information to be made available to consumers, either through annual reports, on the internet;
- Establishment of mechanisms to receive and actively address community complaints in a timely fashion.

The right of consumers to information on health-related parameters of the water supplied to them for domestic purposes is fundamental. However, in many communities, the simple right of access to information will not ensure that individuals are aware of the quality of the water supplied to them; furthermore, the probability of consuming unsafe water is relatively high. The agencies responsible for monitoring should therefore develop strategies for disseminating and explaining the significance of health-related results they obtain. Further information on communication is provided in Chapter 5.