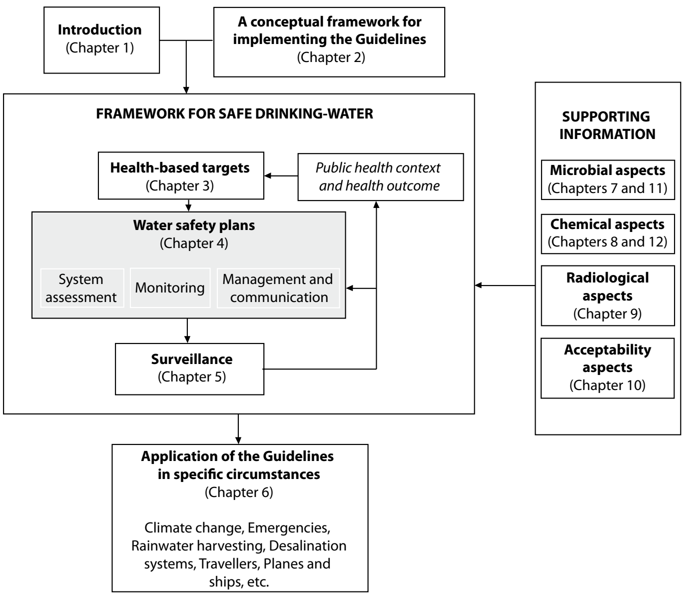
4
Water safety plans



The most effective means of consistently ensuring the safety of a drinking-water supply is through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in the water supply from catchment to consumer. In these Guidelines, such approaches are termed water safety plans (WSPs). The WSP approach has been developed to organize and systematize a long history of management practices applied to drinking-water and to ensure the applicability of these practices to the management of drinking-water quality. WSPs represent an evolution of the concept of sanitary surveys and vulnerability assessments that include and encompass the whole of the water supply system and its operation. The WSP approach draws on many of the principles and concepts from other risk management approaches, in particular the multiple-barrier approach and hazard assessment and critical control points (as used in the food industry).

This chapter focuses on the key principles of WSPs and is not a comprehensive guide to their application in practice. Practical information on how to develop and implement a WSP is available in the supporting documents *Water safety plan manual* and *Water safety planning for small community water supplies* (Annex 1).

WSPs vary in complexity, as appropriate for the situation. In many cases, they will be quite simple, focusing on the key hazards identified for the specific drinking-water supply system. The wide range of examples of control measures given in the following text does not imply that all of these are appropriate in all cases.

WSPs should, by preference, be developed for individual drinking-water systems. For smaller systems, it may be possible to develop generic WSPs by a statutory body or accredited third-party organization. In these settings, guidance on household water storage, handling and use may also be required. Plans dealing with household water should be linked to a hygiene education programme and advice to households in maintaining water safety.

A WSP comprises, as a minimum, the three key components that are the responsibility of the drinking-water supplier in order to ensure that drinking-water is safe. These are:

- a system assessment;
- effective operational monitoring;
- management and communication.

A WSP has three key components, which are guided by health-based targets (see chapter 3) and overseen through drinking-water supply surveillance (see chapter 5). They are:

1) a *system assessment* to determine whether the drinking-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) identifying control measures in a drinking-water system that will collectively control identified risks and ensure that the health-based targets are met. For each control measure identified, an appropriate means of *operational monitoring* should be defined that will ensure that any deviation from required performance is rapidly detected in a timely manner;
3) *management and communication plans* describing actions to be taken during normal operation or incident conditions and documenting the system assessment, including upgrade and improvement planning, monitoring and communication plans and supporting programmes.

The primary objectives of a WSP in ensuring good drinking-water supply practice are the prevention or minimization of contamination of source waters, the reduction or removal of contamination through treatment processes and the prevention of contamination during storage, distribution and handling of drinking-water. These objectives are equally applicable to large piped drinking-water supplies, small community supplies (see section 1.2.6) and household systems and are achieved through:

- development of an 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;
- implementation of a system for operational monitoring of the control measures within the water system;
- timely corrective actions to ensure that safe water is consistently supplied;

- undertaking verification of drinking-water quality to ensure that the WSP is being implemented correctly and is achieving the performance required to meet relevant national, regional and local water quality standards or objectives.

WSPs are a powerful tool for the drinking-water supplier to manage the supply safely. They also assist surveillance by public health authorities. Key benefits for water suppliers implementing WSPs include:

- demonstration of "due diligence";
- improved compliance;
- rationalizing and documenting existing operational procedures, leading to gains in efficiency, improvement of performance and quicker response to incidents;
- better targeted and justification for long-term capital investments based on risk assessment;
- improved management of existing staff knowledge and identification of critical gaps in skills for staff;
- improved stakeholder relationships.

One of the challenges and responsibilities of water suppliers and regulators is to anticipate, plan for and provide for climate variations and weather extremes. WSPs are an effective tool to manage such variations and extremes (see also section 6.1).

Where a defined entity is responsible for a drinking-water supply, its responsibility should include the preparation and implementation of a WSP. This plan should normally be reviewed and agreed upon with the authority responsible for protection of public health to ensure that it will deliver water of a quality consistent with the defined targets.

Where there is no formal service provider, the competent national or regional authority should act as a source of information and guidance on the adequacy of appropriate management of community and individual drinking-water supplies. This will include defining requirements for operational monitoring and management. Approaches to verification in these circumstances will depend on the capacity of local authorities and communities and should be defined in national policy.

Many water suppliers may face practical challenges in initiating, developing and implementing a WSP. These include mistaken perceptions that one prescribed methodology must be followed; that WSP steps must be undertaken with risks managed from source to tap in a defined order; that developing a WSP always requires external expertise; that WSPs supersede, rather than build on, existing good practices; and that WSPs are necessarily complicated and are not appropriate for small supplies.

Although WSP implementation demands a certain minimum standard in terms of the steps involved (Figure 4.1), it is a flexible approach that should rely on the water supplier's existing practices and fit the way that a supplier is organized.

The WSP is a vital step in identifying the hazards and risks associated with the source water catchment, particularly where the water supplier does not manage the catchment, or with established treatment and distribution systems. Starting with existing treatment to ensure that it is operating at its optimum at all times is a vital component, as this is often the key barrier that prevents hazards from reaching

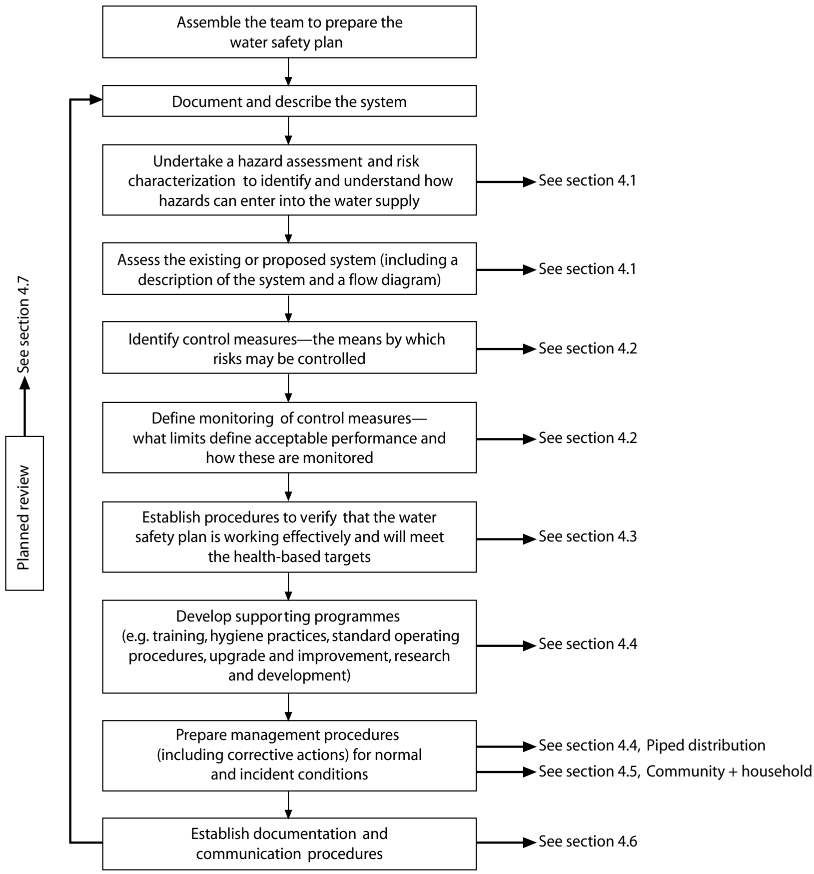


Figure 4.1 Overview of the steps in developing a water safety plan

drinking-water. It must be recognized that even if other hazards are identified in the catchment, remediation may take time, and this should not be a reason for delaying the start of WSP preparation and implementation. Similarly, initiating the process of ensuring that the distribution system is intact and managed appropriately is a vital step that is under the control of the water supplier.

Many of the procedures inherent in the WSP, such as documenting the system and ensuring that standard operating procedures are established for each of the treatment processes and the operation of the distribution system, are simply normal good practice in drinking-water supply. The WSP should therefore build on and improve existing practice.

WSPs should also not be seen as a competing initiative to existing programmes already being undertaken. For example, a programme that addresses non-revenue water (e.g. leakage), although primarily addressing a water quantity issue, is also part of a WSP. A non-revenue water programme would address issues such as intermittent supply and low water pressure, both of which are contributing factors to contamination of drinking-water in the distribution system.

It is recognized that it will not be possible to fully establish a WSP all at once, but the mapping of the system, the identification of the hazards and the assessment of the risks will provide a framework for prioritizing actions and will identify the requirements for continuing improvement as resources become available. They will also identify and help make the case for resource allocation and investment so that they can be targeted to provide the greatest benefit, thus optimizing resources and investment.

In some countries, the regulatory system is relatively complex. A vital component of WSPs and the delivery of safe drinking-water is proper communication and exchange of information between regulators, including environmental authorities, and between regulators or authorities and water suppliers. This is particularly important if resources are to be optimized, and shared information can lead to savings on all sides, while ensuring that drinking-water supplies are improved.

Small supplies remain a significant challenge for many countries, partly because human, technical and financial resources are limited. The introduction of WSPs helps to identify simple and cost-effective steps that can be taken to protect and improve such supplies. It is important that health authorities emphasize the importance of safe drinking-water to the local community and raise the status of the operator's role in the community. It would also be helpful for the relevant authorities to provide a resource or point of contact where operators can obtain advice on and help for WSP implementation.

4.1 System assessment and design

The first stage in developing a WSP is to form a multidisciplinary team of experts with a thorough understanding of the drinking-water system involved. The team should be led by the drinking-water supplier and have sufficient expertise in abstraction, treatment and distribution of drinking-water. Typically, such a team would include individuals involved in each stage of the supply of drinking-water and in many cases representatives from a wider group of stakeholders with collective responsibility for the water supply system from catchment to consumer. Teams could include engineers, catchment and water managers, water quality specialists, environmental or public health or hygienist professionals, operational staff and representatives of consumers or from the community. In most settings, the team will include members from external agencies, including the relevant regulatory agency. For small water supplies, additional external expertise may be useful in addition to operational personnel.

Effective management of the drinking-water system requires a comprehensive understanding of the system, the range and magnitude of hazards and hazardous events that may affect the system and the ability of existing processes and infrastructure to manage actual or potential risks (otherwise known as a *sanitary survey*). It also requires an assessment of capabilities to meet targets. 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 relevant information and consideration of what risks may arise during delivery of water to the consumer.

Assessment of the drinking-water system supports subsequent steps in the WSP in which effective strategies for control of hazards are planned and implemented.

The assessment and evaluation of a drinking-water system are enhanced through an accurate system description, including a flow diagram. The system description should provide an overview of the drinking-water system, including characterization of the source, identification of potential pollution sources in the catchment, measures for resource and source protection, treatment processes, storage and mechanisms for distribution (including piped and non-piped systems). It is essential that the description and the flow diagram of the drinking-water system are conceptually accurate. If the description is not correct, it is possible to overlook potential hazards that may be significant. To ensure accuracy, the system description should be validated by visually checking against features observed on the ground.

> Effective risk management requires the identification of potential hazards and 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);
> - *risk* is the likelihood of identified hazards causing harm in exposed populations in a specified time frame, including the magnitude of that harm and/or the consequences.

Data on the occurrence of pathogens and chemicals in source waters and in drinking-water combined with information concerning the effectiveness of existing controls enable an assessment of whether health-based targets can be achieved with the existing infrastructure. They also assist in identifying catchment management measures, treatment processes and distribution system operating conditions that would reasonably be expected to achieve those health-based targets if improvements are required.

> It may often be more efficient to invest in preventive processes within the catchment than to invest in major treatment infrastructure to manage a hazard.

To ensure the accuracy of the assessment, including an overall estimate of risk, it is essential that all elements of the drinking-water system (catchment, treatment and distribution) are considered concurrently and that interactions among these elements are taken into consideration.

4.1.1 New systems

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 contamination of the drinking-water supply source. These analyses would normally include hydrological analysis, geological assessment and land use inventories to determine potential chemical and radiological contaminants.

When designing new systems, all water quality factors should be taken into account in selecting technologies for abstraction and treatment of new resources. Variations in the turbidity and other parameters of raw surface waters can be considerable, and allowance must be made for this. Treatment plants should be designed to take account of variations known or expected to occur with significant frequency rather than for average water quality; otherwise, for example, 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 drinking-water may be reduced and public health endangered.

4.1.2 Collecting and evaluating available data

Areas that should be taken into consideration as part of the assessment of the drinking-water system include all real or potential hazards and hazardous events associated with each step in the drinking-water system that could result in contamination or interruption of supply. In most cases, consultation with public health and other sectors, including land and water users and all those who regulate activities in the catchment, will be required for the analysis of catchments. A structured approach is important to ensure that significant issues are not overlooked and that areas of greatest risk are identified.

The overall assessment of the drinking-water system should take into consideration any historical water quality data that may assist in understanding source water characteristics and drinking-water system performance both over time and following specific events (e.g. heavy rainfall). For examples of information to consider in assessing components of the drinking-water system, see Module 3 in the supporting document *Water safety plan manual* (Annex 1).

Prioritizing hazards for control

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

The risk associated with each hazard or hazardous event may be described 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 important and less important hazards or hazardous events. The approach used typically involves a semiquantitative matrix.

Simple scoring matrices often apply technical information from guidelines, scientific literature and industry practice with well-informed “expert” judgement based on knowledge and experience of WSP team members, supported by peer review or benchmarking. Scoring is specific for each drinking-water system, as each system is unique. Where generic WSPs are developed for technologies used by small drinking-water systems, the scoring will be specific to the technology rather than the individual drinking-water system.

By using risk ranking, control measures can be prioritized in relation to their significance. A variety of semiquantitative and qualitative approaches to ranking risk can be applied, and Module 3 of the supporting document *Water safety plan manual* (Annex 1) provides a series of practice-based examples. An example of a semiquantitative approach is given in Table 4.1. Application of this matrix relies to a significant extent on expert opinion to make judgements on the public health risk posed by hazards or hazardous events.

Table 4.1 Example of a simple scoring matrix for ranking risks

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

Risk score	< 6	6–9	10–15	> 15
Risk rating	Low	Medium	High	Very high

An example of descriptors that can be used to rate the likelihood of occurrence and severity of consequences is given in Table 4.2. A "cut-off" point must be determined, above which all risks will require immediate attention. There is little value in expending large amounts of effort to consider very low risks.

Control measures

The assessment and planning of control measures should ensure that health-based targets will be met and should be based on hazard identification and risk assessment. The level of control applied to a hazard should be proportional to the associated risk ranking. Assessment of control measures involves:

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

Identification and implementation of control measures should be based on 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 minimizing 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, whereas some hazards may require more than one control measure for effective control. Examples of control measures are provided in the following sections.

> Control measures are activities or processes within the drinking-water supply used to eliminate or significantly reduce the occurrence of a water safety hazard. These measures are applied collectively to ensure that drinking-water consistently meets health-based targets.

All control measures are important and should be afforded ongoing attention. They should be subject to operational monitoring and control, with the means of

Table 4.2 Examples of definitions of likelihood and severity categories that can be used in risk scoring

Item	Rating	Definition
Likelihood categories		
Almost certain	5	Once per day
Likely	4	Once per week
Moderately likely	3	Once per month
Unlikely	2	Once per year
Rare	1	Once every 5 years
Severity categories		
Catastrophic	5	Public health impact
Major	4	Regulatory impact
Moderate	3	Aesthetic impact
Minor	2	Compliance impact
Insignificant	1	No impact or not detectable

monitoring and frequency of data collection based on the nature of the control measure and the rapidity with which change may occur (see section 4.2).

4.1.3 Resource and source protection

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

Hazard identification

Understanding the reasons for variations in raw water quality is important, as it will influence the requirements for treatment, treatment efficiency and the resulting health risk associated with the finished drinking-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. wastewater discharges) and non-point sources (e.g. surface runoff). For example, discharges of municipal wastewater can be a major source of pathogens; urban runoff and livestock can contribute substantial microbial load; body contact recreation can be a source of faecal contamination; and agricultural runoff, including agrochemicals and manure, can lead to increased challenges to treatment.

Whether water is drawn from surface or 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 practices in land use and in containment of hazards is often possible without substantially restricting activities, and collaboration between stakeholders may be a powerful tool to reduce pollution without reducing beneficial development.

Resource and source protection provides the first barrier in protection of drinking-water quality. Where catchment management is beyond the jurisdiction of the drinking-water supplier, the planning and implementation of control measures will require coordination with other agencies. These may include planning authorities, catchment boards, environmental and water resource regulators, road authorities, emergency services and agricultural, industrial and other commercial entities whose activities have an impact on water quality. It may not be possible to apply all aspects of resource and source protection initially; nevertheless, priority should be given to catchment management. This will contribute to a sense of ownership and joint responsibility for drinking-water resources through multistakeholder bodies that assess pollution risks and develop plans for improving management practices for reducing these risks.

Groundwater from deep and confined aquifers is usually microbially safe and chemically stable in the absence of direct contamination; however, shallow or unconfined aquifers can be subject to contamination from discharges or seepages associated with agricultural practices (e.g. pathogens, nitrates and pesticides), on-site sanitation and sewerage (e.g. pathogens and nitrates) and industrial wastes. For examples of hazards and hazardous situations that should be taken into consideration as part of a hazard analysis and risk assessment, see Module 4 in the supporting document *Water safety plan manual* and the supporting documents *Protecting groundwater for health* and *Protecting surface water for health* (Annex 1).

Control measures

Effective resource and source protection includes the following elements:

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

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 (e.g. following heavy rainfall) in order to reduce risk and prevent potential problems in subsequent treatment processes.

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

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.); further information can be found in the supporting document *Protecting groundwater for health* (Annex 1).

For examples of control measures for effective protection of source water and catchments and of water extraction and storage systems, see Module 4 in the supporting document *Water safety plan manual* and the supporting document *Protecting surface water for health* (Annex 1). Further information on the use of indicator organisms in catchment characterization is also available in chapter 4 of the supporting document *Assessing microbial safety of drinking water* (Annex 1).

4.1.4 Treatment

After source water protection, the next barriers to contamination of the drinking-water system are those of water treatment processes, including disinfection and physical removal of contaminants.

Hazard identification

Hazards may be introduced during treatment, or hazardous events may allow contaminants to pass through treatment in significant concentrations. Constituents of drinking-water can be introduced through the treatment process, including chemical additives used in the treatment process or products in contact with drinking-water. Sporadic high turbidity in source water can overwhelm treatment processes, allowing enteric pathogens into treated water and the distribution system. Similarly, suboptimal filtration following filter backwashing can lead to the introduction of pathogens into the distribution system.

For examples of potential hazards and hazardous events that can have an impact on the performance of drinking-water treatment, see Module 3 in the supporting document *Water safety plan manual* (Annex 1).

Control measures

Control measures may include pretreatment, coagulation, flocculation, sedimentation, filtration and disinfection.

Pretreatment includes processes such as roughing filters, microstrainers, off-stream storage and bankside filtration. Pretreatment options may be compatible with a variety of treatment processes ranging in complexity from simple disinfection to membrane processes. Pretreatment can reduce or stabilize the microbial, natural organic matter and particulate load.

Coagulation, flocculation, sedimentation (or flotation) and filtration remove particles, including microorganisms (bacteria, viruses and protozoa). It is important that processes are optimized and controlled to achieve consistent and reliable performance. Chemical coagulation is the most important step in determining the removal efficiency of coagulation, flocculation and 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 hazards 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 pathogenic microorganisms and may in some cases be the only treatment barrier (e.g. for removing *Cryptosporidium* oocysts by direct filtration when chlorine is used as the sole disinfectant).

Application of an adequate concentration of disinfectant is an essential element for most treatment systems to achieve the necessary level of microbial risk reduction. Taking account of the level of microbial inactivation required for the more resistant microbial pathogens through the application of the *Ct* concept (product of disinfectant concentration and contact time) for a particular pH and temperature ensures that other, more sensitive microbes are also effectively controlled. Where disinfection is used, measures to minimize DBP formation should be taken into consideration.

The most commonly used disinfection process is chlorination. Ozonation, ultraviolet irradiation, chloramination and application of 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 some may inactivate many protozoa, including *Giardia* and *Cryptosporidium*. For effective removal or inactivation of protozoal cysts and oocysts, filtration with the aid of coagulation and flocculation (to reduce particles and turbidity) followed by disinfection (by one or a combination of disinfectants) is the most practical method.

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

For examples of treatment control measures, see Module 4 in the supporting document *Water safety plan manual* (Annex 1). Further information can also be found in the supporting document *Water treatment and pathogen control* (Annex 1).

4.1.5 Piped distribution systems

Water treatment should be optimized to prevent microbial growth, corrosion of pipe materials and the formation of deposits.

Maintaining good water quality in the distribution system will depend on the design and operation of the system and on maintenance and survey procedures to prevent contamination and to prevent and remove the accumulation of internal deposits.

Hazard identification

The protection of the distribution system is essential for providing safe drinking-water. Because of the nature of the distribution system, which may include many kilometres of pipe, storage tanks, interconnections with industrial users and the potential for tampering and vandalism, opportunities for microbial and chemical contamination exist. For examples of hazards and hazardous events in piped distribution systems, see Module 3 in the supporting document *Water safety plan manual* (Annex 1).

When contamination by enteric pathogens or hazardous chemicals occurs within the distribution system, it is likely that consumers will be exposed. to the pathogens or chemicals. In the case of pathogen ingress, even where disinfectant residuals are employed to limit microbial occurrence, they 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.

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. Intermittent supplies are not desirable but are very common in many countries and are frequently associated with contamination. The control of water quality in intermittent supplies represents a significant challenge, as the risks of infiltration and backflow increase significantly. The risks 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 household storage is used to overcome intermittent supply, localized use of disinfectants to reduce microbial proliferation may be warranted.

Drinking-water entering the distribution system may contain free-living amoebae and environmental strains of various heterotrophic bacterial and fungal species. Under favourable conditions, amoebae and heterotrophs, including strains of *Citrobacter*, *Enterobacter* and *Klebsiella*, may colonize distribution systems and form biofilms. There is no evidence to implicate the occurrence of most microorganisms from biofilms (one exception is *Legionella*, which can colonize water systems in buildings) with adverse health effects in the general population through drinking-water, with the possible exception of severely immunocompromised people (see the supporting document *Heterotrophic plate counts and drinking-water safety*; Annex 1).

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.

Natural disasters, including flood, drought and earth tremors, may significantly affect piped water distribution systems.

Control measures

Water entering the distribution system must be microbially safe and ideally should also be biologically stable. The distribution system itself must provide a secure barrier to contamination as the water is transported to the user. Maintaining a disinfectant residual throughout the distribution system can provide some protection against recontamination and limit microbial growth problems. Chloramination has proved successful in controlling *Naegleria fowleri* in water and sediments in long pipelines and may reduce the regrowth of *Legionella* within buildings.

Residual disinfectant will provide partial protection against microbial contamination, but it may also mask the detection of contamination through the use of conventional faecal indicator bacteria such as *E. coli*, particularly by resistant organisms. Where a disinfectant residual is used within a distribution system, measures to minimize DBP production should be taken into consideration.

Water distribution systems should be fully enclosed, and storage reservoirs and tanks should be securely roofed with external drainage to prevent contamination.

Control of short-circuiting and prevention of stagnation in both storage and distribution contribute to prevention of microbial growth. A number of strategies can be adopted to maintain the quality of water within the distribution system, including use of backflow prevention devices, maintaining positive pressure throughout the system and implementation of efficient maintenance procedures. It is also important that appropriate security measures be put in place to prevent unauthorized access to or interference with the drinking-water system infrastructure.

Control measures may include using a more stable secondary disinfecting chemical (e.g. chloramines instead of free chlorine), undertaking a programme of pipe replacement, flushing and relining and maintaining positive pressure in the distribution system. Reducing the time that water is in the system by avoiding stagnation in storage tanks, loops and dead-end sections will also contribute to maintaining drinking-water quality. For other examples of distribution system control measures, see Module 4 in the supporting document *Water safety plan manual* (Annex 1). Further information is also available in the supporting document *Safe piped water* (Annex 1).

4.1.6 Non-piped, community and household systems

Hazard identification

For non-piped, community and household drinking-water systems, hazard identification would ideally be performed on a case-by-case basis. In practice, however, reliance is typically placed on general assumptions of hazardous conditions that are relevant for technologies or system types and that may be defined at a national or regional level.

For examples of hazards and hazardous situations potentially associated with various non-piped sources of water, see Module 3 in the supporting documents *Water safety plan manual* and *Water safety planning for small community water supplies* (Annex 1). Further guidance is also provided in the supporting document *Water safety plans* (Annex 1) and in the 1997 volume entitled *Surveillance and control of community supplies* (WHO, 1997).

Control measures

The control measures required ideally 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.

For examples of control measures for various non-piped sources, see Module 4 in the supporting documents *Water safety plan manual* and *Water safety planning for small community water supplies* (Annex 1) and the 1997 report entitled *Surveillance and control of community supplies* (WHO, 1997).

In most cases, contamination of groundwater supplies can be controlled by a combination of simple measures. In the absence of fractures or fissures, which may allow rapid transport of contaminants to the source, groundwater in confined or deep aquifers will generally be free of pathogenic microorganisms. Bores should be encased to a reasonable depth, and boreheads should be sealed to prevent ingress of surface water or shallow groundwater.

Rainwater harvesting systems, particularly those involving storage in aboveground tanks, can be a relatively safe supply of water (see section 6.2). The principal sources of contamination are birds, small mammals and debris collected on roofs. The impact of these sources can be minimized by simple measures: 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 mammals) and inlet pipes to tanks should include leaf litter strainers. First-flush diverters, which prevent the initial roof-cleaning wash of water (20–25 litres) from entering tanks, are recommended. If first-flush diverters are not available, a detachable downpipe can be used manually to provide the same result.

In general, surface waters will require at least disinfection, and usually also filtration, to ensure microbial safety. The first barrier is based on minimizing contamination from human waste, livestock and other hazards at the source.

The greater the protection of the water source, the less the reliance on treatment or disinfection. Water should be protected during storage and delivery to consumers by ensuring that the distribution and storage systems are enclosed. This applies to both community piped systems and vendor-supplied water (section 6.3). For water stored in the home, protection from contamination can be achieved by use of enclosed or otherwise safely designed storage containers that prevent the introduction of hands, dippers or other extraneous sources of contamination.

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

Model WSPs may be developed generically for the following types of water supply:

- groundwater from protected boreholes or wells with mechanized pumping;
- conventional treatment of water;
- multistage filtration;
- storage and distribution through supplier-managed piped systems;
- storage and distribution through community-managed piped systems;
- water vendors;
- water on conveyances (planes, ships and trains);
- tubewells from which water is collected by hand;
- springs from which water is collected by hand;
- simple protected dug wells;
- rainwater catchments.

Guidance is available regarding how water safety may be ensured for household water collection, transport and storage (see the supporting document *Managing water in the home*; Annex 1). This should be used in conjunction with hygiene education programmes to support health promotion in order to reduce water-related disease.

4.1.7 Validation

For the WSP to be relied on for anticipating and managing the hazards and hazardous events for which it was set in place, it needs to be supported by accurate and reliable technical information. Validation is concerned with obtaining evidence on the performance of control measures. Depending on the type of control, validation can be done by site inspection, using existing data and literature or targeted monitoring programmes to demonstrate performance under normal and exceptional circumstances.

> Validation is an investigative activity to identify the effectiveness of a control measure. It is typically an intensive activity when a system is initially constructed or rehabilitated. It provides information on reliably achievable water quality in preference to assumed values and also to define the operational criteria required to ensure that the control measure contributes to effective control of hazards.

Validation of treatment processes is required to show that the treatment processes can operate as required and achieve required levels of hazard reduction. In the case of microbial hazards, these required levels commonly take the form of performance targets based on the use of reference pathogens (see section 7.2). Validation can be undertaken during pilot stage studies or during initial implementation of a new or modified water treatment system. It is also a useful tool in the optimization of existing treatment processes.

The first stage of validation is to consider data and information that already exist. Sources include the scientific literature, relevant industry bodies, partnering and benchmarking with larger authorities, manufacturers' specifications and historical data. This stage will inform the testing requirements. It is important that data used in validation are relevant for system-specific conditions, as variations in water composition and quality, for example, may have a large impact on the efficacy of control measures.

Validation is not used for day-to-day management of drinking-water supplies; as a result, microbial parameters that may be inappropriate for operational monitoring can be used, and the lag time for return of results and additional costs from pathogen measurements can often be tolerated. Parameters should be chosen to reflect the microorganisms being targeted by treatment (see section 7.2). Increasingly, indicator parameters are being used in validation. For example, coliphage can be used to assess the effectiveness of virus removal by filtration processes or to measure the effectiveness of disinfection processes, whereas *Clostridium perfringens* can be used to measure the effectiveness of the removal of protozoa by filtration processes.

Validation should not be confused with routine operational monitoring, which is designed to show that validated control measures continue to work effectively (see section 4.2). The validation process often leads to improvements in operating performance through the identification of the most effective and robust operating modes. Additional benefits of the validation process may include identification of more suitable operational monitoring parameters for unit performance.

4.1.8 Upgrade and improvement

The assessment of the drinking-water system may indicate that existing practices and control measures may not ensure drinking-water safety. In some instances, all that may be needed is to review, document and formalize these practices and address any areas where improvements are required; in others, major infrastructure changes may be needed. The assessment of the system should be used as a basis to develop a plan to address identified needs for full implementation of a WSP.

Improvement of the drinking-water system may encompass a wide range of issues, such as:

- capital works;
- training;
- enhanced operational procedures;
- community consultation programmes;
- research and development;
- developing incident protocols;
- communication and reporting.

Upgrade and improvement plans can include short-term (e.g. 1 year) or long-term programmes. Short-term improvements might include, for example, improvements to community consultation and the development of community awareness programmes. Long-term capital works projects could include covering of water storages or enhanced coagulation and filtration.

Implementation of improvement plans may have significant budgetary implications and therefore may require detailed analysis and careful prioritization 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 made in isolation from other aspects of drinking-water supply that compete for limited financial resources. Priorities will need to be established, and improvements may need to be phased in over a period of time.

4.2 Operational monitoring and maintaining control

Operational monitoring is a planned and routine set of activities used to determine that control measures continue to work effectively. In operational monitoring, the drinking-water supplier monitors each control measure in a timely manner with the objectives to enable effective system management and to ensure that health-based targets are achieved.

4.2.1 Determining system control measures

The identity and number of control measures are system specific and will be determined by the number and nature of hazards and hazardous events as well as the magnitude of associated risks.

Control measures should reflect the likelihood and consequences of loss of control. Control measures have a number of operational requirements, including the following:

- operational monitoring parameters that can be measured and for which limits can be set to define the operational effectiveness of the activity;
- operational monitoring parameters that can be monitored with sufficient frequency to reveal failures in a timely fashion;

- procedures for corrective action that can be implemented in response to deviation from limits.

4.2.2 Selecting operational monitoring parameters

Operational monitoring can include measurement of parameters or observational activities. 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 the opportunity for an appropriate response. Examples include measurable variables, such as chlorine residuals, pH and turbidity, or observable factors, such as the integrity of vermin-proof screens.

> Operational monitoring assesses the performance of control measures at appropriate time intervals. The intervals may vary widely—for example, from online control of residual chlorine to quarterly verification of the integrity of the plinth surrounding a well.

Enteric pathogens or indicator organisms are often of limited use for operational monitoring, because the time taken to process and analyse water samples does not allow operational adjustments to be made prior to supply.

A range of parameters can be used in operational monitoring:

- For source waters, these include turbidity, ultraviolet absorbency, algal growth, flow and retention time, colour, conductivity, local meteorological events and integrity of protective (e.g. fences) or abstraction infrastructures (e.g. well seals) (see the supporting documents *Protecting groundwater for health* and *Protecting surface water for health*; Annex 1).
- For treatment, parameters may include disinfectant concentration and contact time, ultraviolet intensity, pH, light absorbency, membrane integrity, turbidity and colour (see the supporting document *Water treatment and pathogen control*; Annex 1).
- In piped distribution systems, operational monitoring parameters may include the following:
  - *Chlorine residual monitoring* provides a rapid indication of problems that will direct measurement of 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 pipework has a high oxidant demand due to growth of bacteria.
  - *Oxidation–reduction potential* (or redox potential) measurement can also be used in the operational monitoring of disinfection efficacy. It is possible to define a minimum level of oxidation–reduction potential necessary to ensure effective disinfection. This value has to be determined on a case-by-case basis; universal values cannot be recommended. Further research and evaluation of oxidation–reduction potential as an operational monitoring technique are highly desirable.
  - *Heterotrophic bacteria* present in a supply can be a useful indicator of changes, such as increased microbial growth potential, increased biofilm

activity, extended retention times or stagnation and a breakdown of integrity of the system. The numbers of heterotrophic bacteria present in a supply may reflect the presence of large contact surfaces within the treatment system, such as in-line filters, and may not be a direct indicator of the condition within the distribution system (see the supporting document *Heterotrophic plate counts and drinking-water safety*; Annex 1).

— *Pressure measurement and turbidity* are also useful operational monitoring parameters in piped distribution systems (see the supporting document *Turbidity: information for regulators and operators of water supplies*; Annex 1).

Guidance for management of distribution system operation and maintenance is available (see the supporting document *Safe piped water*; Annex 1) and includes the development of a monitoring programme for water quality and other parameters such as pressure.

Examples of operational monitoring parameters are provided in Table 4.3.

4.2.3 Establishing operational and critical limits

Control measures need to have defined limits for operational acceptability—termed operational limits—that can be applied to operational monitoring parameters. Operational limits should be defined for parameters applying to each control measure. If monitoring shows that an operational limit has been exceeded, then predetermined corrective actions (see section 4.4) need to be applied. The detection of the deviation and implementation of corrective action should be possible in a time frame adequate to maintain performance and water safety.

For some control measures, a second series of "critical limits" may also be defined, outside of which confidence in water safety would be lost. Deviations from critical limits will usually require urgent action, including immediate notification of the appropriate health authority.

Operational and critical limits can be upper limits, lower limits, a range or an "envelope" of performance measures.

4.2.4 Non-piped, community and household systems

Generally, surface water or shallow groundwater should not be used as a source of drinking-water without sanitary protection or treatment.

Monitoring of water sources (including rainwater tanks) by community operators or households will typically involve periodic sanitary inspection (for details, see the 1997 volume entitled *Surveillance and control of community supplies*; WHO, 1997). 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 preferably related to activities that are under the control of the operator and that may affect water quality. The links to action from the results of operational monitoring should be clear, and training will be required.

Operators should also undertake regular physical assessments of the water, especially after heavy rains, to monitor whether any obvious changes in water quality have occurred (e.g. changes in colour, odour, taste or turbidity).

Maintaining the quality of water during collection and manual transport is the responsibility of the household. Good hygiene practices are required and should be supported through hygiene education. Hygiene education programmes should provide households and communities with skills to monitor and manage their water hygiene.

Table 4.3 Examples of operational monitoring parameters that can be used to monitor control measures

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 concentration × contact time)					✓	
Disinfectant residual					✓	✓
Oxidation–reduction potential					✓	
DBPs					✓	✓
Heterotrophic bacteria					✓	✓
Hydraulic pressure						✓

If treatment is applied to water from community sources (such as boreholes, wells and springs) as well as household rainwater collection, then operational monitoring is advisable. When household treatment is introduced, it is essential that information (and, where appropriate, training) be provided to users to ensure that they understand basic operational monitoring requirements.

4.3 Verification

Verification provides a final check on the overall performance of the drinking-water supply chain and the safety of drinking-water being supplied to consumers. Verification should be undertaken by the surveillance agency; water suppliers may also undertake internal verification programmes.

For microbial verification, testing is typically for faecal indicator bacteria in treated water and water in distribution. For verification of chemical safety, testing for chemicals of concern may be at the end of treatment, in distribution or at the point of consumption (depending on whether the concentrations are likely to change in distribution). Trihalomethanes and haloacetic acids are the most common DBPs and occur at among the highest concentrations in drinking-water. Under many circumstances, they can serve as a suitable measure that will reflect the concentration of a wide range of related chlorinated DBPs.

> In addition to operational monitoring of the performance of the individual components of a drinking-water system, it is necessary to undertake final *verification* for reassurance that the system as a whole is operating safely. Verification may be undertaken by the supplier, by an independent authority or by a combination of these, depending on the administrative regime in a given country. It typically includes testing for faecal indicator organisms and hazardous chemicals, as well as auditing that WSPs are being implemented as intended and are working effectively.

Frequencies of sampling should reflect the need to balance the benefits and costs of obtaining more information. Sampling frequencies are usually based on the population served or on the volume of water supplied, to reflect the increased population risk. Frequency of testing for individual characteristics will also depend on variability. Sampling and analysis are required most frequently for microbial and less often for chemical constituents. This is because even brief episodes of microbial contamination can lead directly to illness in consumers, whereas episodes of chemical contamination that would constitute an acute health concern, in the absence of a specific event (e.g. chemical overdosing at a treatment plant), are rare. Sampling frequencies for water leaving treatment depend on the quality of the water source and the type of treatment.

Plans should be developed to respond to results that do not meet water quality targets. These should include investigation of the cause of non-compliance and, where necessary, corrective action, such as boil water advisories. Repeated failure to meet targets should lead to review of the WSP and development of improvement plans.

4.3.1 Microbial water quality

Verification of the microbial quality of drinking-water typically includes testing for *Escherichia coli* as an indicator of faecal pollution. In practice, testing for thermotolerant coliform bacteria can be an acceptable alternative in many circumstances. Although *E. coli* is useful, it has limitations. Enteric viruses and protozoa are more resistant to disinfection; consequently, the absence of *E. coli* will not necessarily indicate freedom from these organisms. Under certain circumstances, the inclusion of more resistant indicators, such as bacteriophages and/or bacterial spores, should be considered (see section 7.4).

Verification of the microbial quality of water in supply must be designed to ensure the best possible chance of detecting contamination. Sampling should therefore account for potential variations of water quality in distribution. This will normally mean taking account of locations and of times of increased likelihood of contamination.

Faecal contamination will not be distributed evenly throughout a piped distribution system. In systems where water quality is good, this significantly reduces the probability of detecting faecal indicator bacteria in the relatively few samples collected.

The chances of detecting contamination in systems reporting predominantly negative results for faecal indicator bacteria can be increased by using more frequent presence/absence testing. Presence/absence testing can be simpler, faster and less expensive than quantitative methods. Comparative studies of the presence/absence and quantitative methods demonstrate that the presence/absence methods can maximize the detection of faecal indicator bacteria. However, presence/absence testing is appropriate only in a system where the majority of tests for indicator organisms provide negative results.

The more frequently the water is examined for faecal indicator organisms, the more likely it is that contamination will be detected. Frequent examination by a simple method is more valuable than less frequent examination by a complex test or series of tests.

The nature and likelihood of contamination can vary seasonally, with rainfall and with other local conditions. Sampling should normally be random but should be increased at times of epidemics, flooding or emergency operations or following interruptions of supply or repair work.

Recommended minimum sample numbers for verification of the microbial quality of drinking-water are shown in Table 4.4.

4.3.2 Chemical water quality

Issues that need to be addressed in developing chemical verification 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.

For a given chemical, the location and frequency of sampling will be determined by its principal sources (see chapter 8) and variability in its concentration. Substances that do not change significantly in concentration over time require less frequent sampling than those that might vary significantly.

In many cases, analysis of source water quality once per year, or even less, may be adequate, particularly in stable groundwaters, where the concentrations of naturally occurring substances of concern will vary very slowly over time. Concentrations of naturally occurring substances are likely to be more variable in surface waters, and surface waters therefore may require a greater number of samples, depending on the contaminant and its importance.

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 constituents whose concentrations do not change during delivery. However, for those constituents whose concentrations can change during distribution, sampling should be undertaken following consideration of the behaviour or source of the specific substance. Samples should include points near the extremities of the distribution system and taps connected directly to the mains in houses and large

Table 4.4 Recommended minimum sample numbers for faecal indicator testing in distribution systems[a]

Type of water supply and population	Total number of samples per year
Point sources	Progressive sampling of all sources over 3- to 5-year cycles (maximum)
Piped supplies	
< 5000	12
5000–100 000	12 per 5000 population
> 100 000–500 000	12 per 10 000 population plus an additional 120 samples
> 500 000	12 per 50 000 population plus an additional 600 samples

[a] Parameters such as chlorine, turbidity and pH should be tested more frequently as part of operational and verification monitoring.

multioccupancy buildings. Lead, for example, should be sampled at consumers' taps, as the source of lead is usually service connections or plumbing in buildings.

For further information, see the supporting document *Chemical safety of drinking-water* (Annex 1).

4.3.3 Source waters

Verification testing of source waters is particularly important where there is no water treatment. It will also be useful following failure of the treatment process or as part of an investigation of a waterborne disease outbreak. The frequency of testing will depend on the reason for carrying out the sampling. Testing frequency may be:

- on a regular basis (the frequency of verification testing will depend on several factors, including the size of the community supplied, the reliability of the quality of the drinking-water or degree of treatment and the presence of local risk factors);
- on an occasional basis (e.g. random or during visits to community-managed drinking-water supplies);
- increased following degradation of source water quality resulting from predictable incidents, emergencies or unplanned events considered likely to increase the potential for a breakthrough in contamination (e.g. following a flood, upstream spills).

Prior to commissioning a new drinking-water supply, a wider range of analyses should be carried out, including parameters identified as potentially being present from a review of data from similar supplies or from a risk assessment of the source.

4.3.4 Piped distribution systems

The choice of sampling points will be dependent on the individual water supply. The nature of the public health risk posed by pathogens and the contamination potential throughout distribution systems mean that collection of samples for microbial analysis (and associated parameters, such as chlorine residual, pH and turbidity) will typically be done frequently and from dispersed sampling sites. Careful consideration of sampling points and frequency is required for chemical constituents that arise from piping and plumbing materials and that are not controlled through their direct regulation and for constituents whose concentrations change in distribution, such as trihalomethanes. The use of stratified random sampling in distribution systems has proven to be effective.

4.3.5 Community-managed supplies

If the performance of a community drinking-water 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 drinking-water systems have adopted *quantitative service indicators* (i.e. quality, quantity, accessibility, coverage, affordability and continuity) for application at community, regional and national levels. Usual practice would be to include the critical parameters for microbial quality (normally *E. coli*, chlorine, turbidity and pH) and for a sanitary inspection to be carried out. Methods for these tests must be standardized and approved. It is recommended that field test kits be validated for performance against reference or standard methods and approved for use in verification testing.

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

Periodic testing and sanitary inspection of community drinking-water supplies should typically be undertaken by the surveillance agency and should assess microbial hazards and known problem chemicals (see also chapter 5). Frequent sampling is unlikely to be possible, and one approach is therefore a rolling programme of visits to ensure that each supply is visited once every 3–5 years. The primary purpose is to inform strategic planning and policy rather than to assess compliance of individual drinking-water supplies. Comprehensive analysis of the chemical quality of all sources is recommended prior to commissioning as a minimum and preferably every 3–5 years thereafter.

Advice on the design of sampling programmes and on the frequency of sampling for community supplies is given in the 1997 volume, *Surveillance and control of community supplies* (WHO, 1997).

4.3.6 Quality assurance and quality control

Appropriate quality assurance and analytical quality control procedures should be implemented for all activities linked to the production of drinking-water quality data. These procedures will ensure that the data are fit for purpose—in other words, that the results produced are of adequate accuracy. Fit for purpose, or adequate accuracy, will be defined in the water quality monitoring programme, which will include a statement about accuracy and precision of the data. Because of the wide range of substances, methods, equipment and accuracy requirements likely to be involved in the monitoring of drinking-water, many detailed, practical aspects of analytical quality control are concerned. These are beyond the scope of this publication.

The design and implementation of a quality assurance programme for analytical laboratories are described in detail in *Water quality monitoring: A practical guide to the* *design and implementation of freshwater quality studies and monitoring programmes* (Bartram & Ballance, 1996). The relevant chapter relates to standard ISO/IEC 17025:2005, *General requirements for the competence of testing and calibration laboratories*, which provides a framework for the management of quality in analytical laboratories.

Guidance on sampling is given in the International Organization for Standardization (ISO) standards listed in Table 4.5.

4.3.7 Water safety plans

In addition to testing of water quality, verification should include audits of WSPs to demonstrate that the plans have been properly designed, are being implemented correctly and are effective. Factors to consider include the following:

- all significant hazards and hazardous events have been identified;
- appropriate control measures have been included;
- appropriate operational monitoring procedures have been established;
- appropriate operational limits have been defined;
- corrective actions have been identified;
- appropriate verification monitoring procedures have been established.

Audits can be undertaken as part of internal or external reviews and may form part of surveillance by independent authorities. Auditing can have both an assessment and a compliance-checking function. Further information can be found in the supporting document *A practical guide to auditing water safety plans* (Annex 1).

4.4 Management procedures for piped distribution systems

Much of a management plan will describe actions to be taken to maintain optimal operation under normal operating conditions. These will include both responses to normal variations in operational monitoring parameters and responses when operational monitoring parameters reach critical limits. All activities, including standard operating procedures applied during normal conditions and planned responses to incidents and emergencies, should be documented.

> Effective management implies definition of actions to be taken during normal operational conditions, of actions to be taken in specific "incident" situations where a loss of control of the system may occur and of procedures to be followed in unforeseen (emergency) situations. Management procedures should be documented alongside system assessment, monitoring plans, supporting programmes and communication required to ensure safe operation of the system.

A significant deviation in operational monitoring where a critical limit is exceeded (or in verification) is often referred to as an "incident". An incident is any situation in which there is reason to suspect that water being supplied for drinking may be, or may become, unsafe (i.e. confidence in water safety is lost). As part of a WSP, management procedures should be defined for response to predictable incidents as well as unpredictable incidents and emergencies.

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 organizations beyond the drinking-water supplier, particularly the public health authorities.

Table 4.5 International Organization for Standardization (ISO) standards for water quality giving guidance on sampling[a]

ISO standard no.	Title (water quality)
5667-1:2006	Sampling—Part 1: Guidance on the design of sampling programmes and sampling techniques
5667-3:2003	Sampling—Part 3: Guidance on the preservation and handling of water samples
5667-4:1987	Sampling—Part 4: Guidance on sampling from lakes, natural and man-made
5667-5:2006	Sampling—Part 5: Guidance on sampling of drinking water and water from treatment works and piped distribution systems
5667-6:2005	Sampling—Part 6: Guidance on sampling of rivers and streams
5667-11:2009	Sampling—Part 11: Guidance on sampling of groundwaters
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
5667-20:2008	Sampling—Part 20: Guidance on the use of sampling data for decision making—Compliance with thresholds and classification systems
5667-21:2010	Sampling—Part 21: Guidance on sampling of drinking water distributed by tankers or means other than distribution pipes
5667-23:2011	Sampling—Part 23: Guidance on passive sampling in surface waters
5668-17:2008	Sampling—Part 17: Guidance on sampling of bulk suspended sediments
13530:2009	Guidance on analytical quality control for chemical and physicochemical water analysis
17381:2003	Selection and application of ready-to-use test kit methods in water analysis

[a] ISO has also established quality management standards relating to drinking-water supply, including ISO 24510:2007, Activities relating to drinking water and wastewater services—Guidelines for the assessment and for the improvement of the service to users; and ISO 24512:2007, Activities relating to drinking water and wastewater services—Guidelines for the management of drinking water utilities and for the assessment of drinking water services.

Incident response plans typically comprise:

- accountabilities and contact details for key personnel, often including several organizations and individuals;
- lists of measurable indicators and limit values/conditions that would 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 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.

Staff should be trained in response procedures to ensure that they can manage incidents or emergencies effectively. Incident and emergency response plans should be periodically 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 should be undertaken involving all concerned staff. The investigation should consider factors such as:

- the cause of the problem;
- how the problem was first identified or recognized;
- the most essential actions required;
- any communication problems that arose, and how they were addressed;
- the immediate and longer-term consequences;
- how well the emergency response plan functioned.

Appropriate documentation and reporting of the incident or emergency should also be established. The organization should learn as much as possible from the incident or emergency to improve preparedness and planning for future incidents. Review of the incident or emergency may indicate necessary amendments to the WSP and existing protocols.

The preparation of clear procedures, definition of accountability and provision of equipment for the sampling and storing of 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.

4.4.1 Predictable incidents ("deviations")

Many incidents (e.g. exceedance of a critical limit) can be foreseen, and management plans can specify resulting actions. Actions may include, for example, temporary change of water sources (if possible), increasing coagulation dose, use of backup disinfection or increasing disinfectant concentrations in distribution systems.

4.4.2 Unplanned events

Some scenarios that lead to water being considered potentially unsafe might not be specifically identified within incident response 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 general incident response plan should 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.

A protocol for situation assessment and declaring incidents would be provided in a general incident response plan that includes 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 general incident responses depends on the experience, judgement and skill of the personnel operating and managing the drinking-water supply. However, generic activities that are common in response to many incidents can be incorporated within general incident response plans. 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 bypassing 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.

4.4.3 Emergencies

Water suppliers should develop plans to be invoked in the event of an emergency. These plans should consider potential natural disasters (e.g. earthquakes, floods, damage to electrical equipment by lightning strikes), accidents (e.g. spills in the watershed, interruptions in electricity supply), damage to treatment plant and distribution system and human actions (e.g. strikes, sabotage). Emergency plans should clearly specify responsibilities for coordinating measures to be taken, a communication plan to alert and inform users of the drinking-water supply and plans for providing and distributing emergency supplies of drinking-water.

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 of authorities internal and external to the organization;
- plans for emergency drinking-water supplies;
- communication protocols and strategies, including notification procedures (internal, regulatory body, media and public);
- mechanisms for increased public health surveillance.

Response plans for emergencies and unforeseen events involving microorganisms or chemicals should also include the basis for issuing boil water advisories (see section 7.6.1) and water avoidance advisories (see section 8.7.10). The objective of the advisory should be taken in the public interest.. Therefore, the advisory should be issued after rapid, but careful, consideration of available information and conclusion that there is an ongoing risk to public health that outweighs any risk from the advice to boil or avoid water. The advisory will typically be managed by public health authorities. A decision to close a drinking-water supply carries an obligation to provide an alternative safe supply and is very rarely justifiable because of the adverse effects, especially to health, of restricting access to water. Specific actions in the event of a guideline exceedance or an emergency are discussed in section 7.6 (microbial hazards) and section 8.7 (chemical hazards); more general considerations are discussed in section 6.7. "Practice" emergencies are an important part of the maintenance of readiness for emergencies. They help to determine the potential actions that can be taken in different circumstances for a specific water supply.

4.4.4 Preparing a monitoring plan

Programmes should be developed for operational and verification monitoring and documented as part of a WSP, detailing the strategies and procedures to follow for monitoring the various aspects of the drinking-water system. The monitoring plans should be fully documented and should include the following information:

- parameters to be monitored;
- sampling location and frequency;
- sampling methods and equipment;
- schedules for sampling;
- references to corrective action procedures, including responsibilities;
- qualifications and certification requirements for testing laboratories;
- 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.

4.4.5 Supporting programmes

Many actions are important in ensuring drinking-water safety but do not directly affect drinking-water quality and are therefore not control measures. These are referred to as "supporting programmes" and should also be documented in a WSP. Supporting programmes could involve:

> Actions that are important in ensuring drinking-water safety but do not directly affect drinking-water quality are referred to as supporting programmes.

- controlling access to treatment plants, catchments and reservoirs and implementing the appropriate security measures to prevent transfer of hazards from people when they do enter source water;
- developing verification protocols for the use of chemicals and materials in the drinking-water supply—for instance, to ensure the use of suppliers that participate in quality assurance programmes;
- using designated equipment for attending to incidents such as mains bursts (e.g. equipment should be designated for potable water work only and not for sewage work);
- training and educational programmes for personnel involved in activities that could influence drinking-water safety; training should be implemented as part of induction programmes and frequently updated;
- research and development to improve understanding of water quality, including the quality of source waters, and treatment.

Supporting programmes will consist almost entirely of items that drinking-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;
- audit of practices to check that they are being used, including taking corrective actions in case of non-conformance.

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

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

Supporting programmes can be extensive, be varied and involve multiple organizations and individuals. Many supporting programmes involve water resource protection measures and typically include aspects of land use control. Some water resource protection measures are engineered, such as effluent treatment processes and stormwater management practices that may be used as control measures.

4.5 Management of community and household water supplies

Community-managed drinking-water supplies worldwide are more frequently contaminated than larger drinking-water supplies, may be more prone to operating discontinuously (or intermittently) and break down or fail more frequently.

To ensure safe drinking-water, the focus in small supplies should be on:

- informing the public;
- assessing the water supply to determine whether it is able to meet identified health-based targets (see section 4.1);
- monitoring identified control measures and training operators to ensure that all likely hazards can be controlled and that risks are maintained at a tolerable level (see section 4.2);
- operational monitoring of the drinking-water system (see section 4.2);
- implementing systematic water quality management procedures (see section 4.4), including documentation and communication (see section 4.6);
- establishing appropriate incident response protocols (usually encompassing actions at the individual supply, backed by training of operators, and actions required by local or national authorities) (see sections 4.4.2 and 4.4.3); and

- developing programmes to upgrade and improve existing water delivery (usually defined at a national or regional level rather than at the level of individual supplies) (see section 4.1.8).

For small point sources serving communities or individual households, the emphasis should be on selecting source water of the best available quality and on protecting its quality by the use of multiple barriers (usually within source protection) and maintenance programmes. Whatever the source (groundwater, surface water or rainwater tanks), communities and householders should assure themselves that the water is safe to drink. Generally, surface water and shallow groundwater under the direct influence of surface water (which includes shallow groundwater with preferential flow paths) should receive treatment.

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 of waterborne disease. The essential parameters of water quality are *E. coli*—thermotolerant (faecal) coliforms are accepted as suitable substitutes—and chlorine residual (if chlorination is practised). These should be supplemented, where appropriate, by pH adjustment (if chlorination is practised) and measurement of turbidity.

These parameters may be measured on site using relatively unsophisticated testing equipment, and improved and relatively low cost systems continue to be developed. 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 impractical.

Other health-related parameters of local significance should also be measured. The overall approach to control of chemical contamination is outlined in chapter 8.

4.6 Documentation and communication

Documentation of a WSP should include:

- description and assessment of the drinking-water system (see section 4.1), including programmes to upgrade and improve existing water delivery (see section 4.1.8);
- the plan for operational monitoring and verification of the drinking-water system (see sections 4.2 and 4.3);
- water safety management procedures for normal operation, incidents (specific and general) and emergency situations (see sections 4.4.1, 4.4.2 and 4.4.3), including communication plans; and
- description of supporting programmes (see section 4.4.5).

Records are essential to review the adequacy of the WSP and to demonstrate the adherence of the drinking-water system to the WSP. Several types of records are generally kept:

- supporting documentation for developing the WSP, including validation;
- records and results generated through operational monitoring and verification;
- outcomes of incident investigations;

- documentation of methods and procedures used;
- records of employee training programmes.

By tracking records generated through operational monitoring and verification, an operator or manager can detect that a process is approaching its operational or critical limit. Review of records can be instrumental in identifying trends and in making operational adjustments. Periodic review of WSP records is recommended so that trends can be noted and appropriate actions decided upon and implemented. Records are also essential when surveillance is implemented through auditing-based approaches.

Communication strategies should include:

- procedures for promptly advising of any significant incidents within the drinking-water supply, including notification of the public health authority;
- summary information to be made available to consumers—for example, through annual reports and on the Internet;
- establishment of mechanisms to receive and actively address community complaints in a timely fashion.

The right of consumers to health-related information on 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 may be relatively high. The agencies responsible for monitoring should therefore develop strategies for disseminating and explaining the significance of health-related information. Further information on communication is provided in section 5.5.

4.7 Planned review

4.7.1 Periodic review

WSPs should not be regarded as static documents. They need to be regularly reviewed and revised to ensure that they are functioning correctly and that they are kept up to date in light of changes in water systems or new developments. Reviews should consider:

- data collected as part of monitoring processes;
- changes to water sources and catchments;
- changes to treatment, demand and distribution;
- implementation of improvement and upgrade programmes;
- revised procedures;
- emerging hazards and risks.

4.7.2 Post-incident review

WSPs should also be reviewed following incidents and emergencies to ensure that, where possible, incidents do not recur and, where this is not possible (e.g. floods), to reduce impacts. Post-incident reviews may identify areas for improvement and the need for revision of WSPs.