Chapter 2: Management of community supplies

Contents

List of tables

List of figures

2.1 Introduction

This chapter discusses good management practices for community drinking-water supplies. A community drinking-water supply is a reticulated, publicly or privately owned, drinking-water supply connecting at least two buildings on separate titles, and serving at least 1500 person days a year (eg, 25 people at least 60 days per year). An integrated management system should be designed to meet the requirements of the *Drinking-water Standards for New Zealand 2005 (revised 2008)* (DWSNZ), statutory requirements and the consumers' needs, as well as environmental and cultural considerations.

The most important constituents of drinking-water are undoubtedly those that are capable of having a direct impact on public health. It is up to the water suppliers to demonstrate to their consumers that the management of the water supply system is being undertaken in a responsible and efficient manner.

The proper management of a water supply system includes:

1. awareness and understanding of the physical and operational components of the system
2. adopting risk, quality assurance and asset management procedures in the operation of the water supply
3. maintaining a surveillance programme to confirm that all systems are operating effectively
4. establishing a preventive and remedial actions programme
5. establishing effective monitoring programmes to test compliance with the drinking-water quality standards
6. being aware of the requirements set down by statutory and consumer needs
7. having the ability to respond to consumer and community needs
8. establishing communication lines and techniques.

This chapter covers items 2–4 in some detail, and necessarily overlaps with items 1 and 5–8, which are covered in other chapters.

Chapters 3 and 4 cover the selection and protection of water sources; Chapters 5–11 cover compliance issues; Chapters 12–15 discuss treatment processes (including disinfection); Chapter 16 discusses distribution system operations and maintenance. Chapter 17 covers monitoring. Consumer satisfaction is important, especially with respect to the aesthetic quality of the water supply, refer Chapter 18: aesthetic considerations. Management of small supplies appears in Chapter 19.

Some management issues are covered in ANSI/AWWA Standards G series, see list on **http://www.awwa.org/files**

EnHealth (2012) developed a risk resource to help local governments in Australia manage environmental health risks, including water supplies. The resource raises awareness of how to minimise the financial, health and reputation risks related to the environmental health responsibilities of local governments.

Water Research Australia (WRA 2015) produced a good practice guide for water supply management laid out in a user friendly format of check points and actions.

Water safety plans (WSPs) contribute to improved O&M by supporting the systematic assessment, prioritisation and management of risks from catchment to consumer, including those related to inadequate O&M. **Operations** refers to the day-to-day "running" of a water supply system under normal or emergency conditions. **Maintenance** involves (a) scheduled or planned activities under normal operating conditions to maintain operational systems, equipment and assets essential to supplying safe water to consumers (including the catchment, raw water storage, abstraction, treatment, distribution and customer interface); and (b) unscheduled activities during unforeseen or emergency situations to bring the water supply system back to normal operating conditions. Most maintenance activities require engagement of operational personnel. **O&M are central to successful implementation of WSPs.** Identifying O&M-related hazards, determining and validating associated control measures, monitoring those control measures, preparing standard operating procedures (SOPs) for O&M activities and ensuring sufficient training for O&M staff are essential components of a WSP. The full benefits of a WSP cannot be realised without these key O&M processes. **WSPs drive O&M improvements.** The risk assessment process that underpins WSPs is a mechanism to identify any gaps in a water supply system's O&M practices and the control measures required to manage risk to water quality and service delivery. This gap analysis becomes the platform to drive O&M process improvements (WHO 2018).

2.1.1 Components of a drinking-water supply

The principal features of a drinking-water supply are shown in Figure 2.1, which is reproduced from section 1.8 of the DWSNZ. The format for the information on drinking-water supplies published in the Ministry's *Register of Community Drinking-water Supplies and Suppliers in New Zealand* is based on the schematic approach illustrated in Figure 2.1.

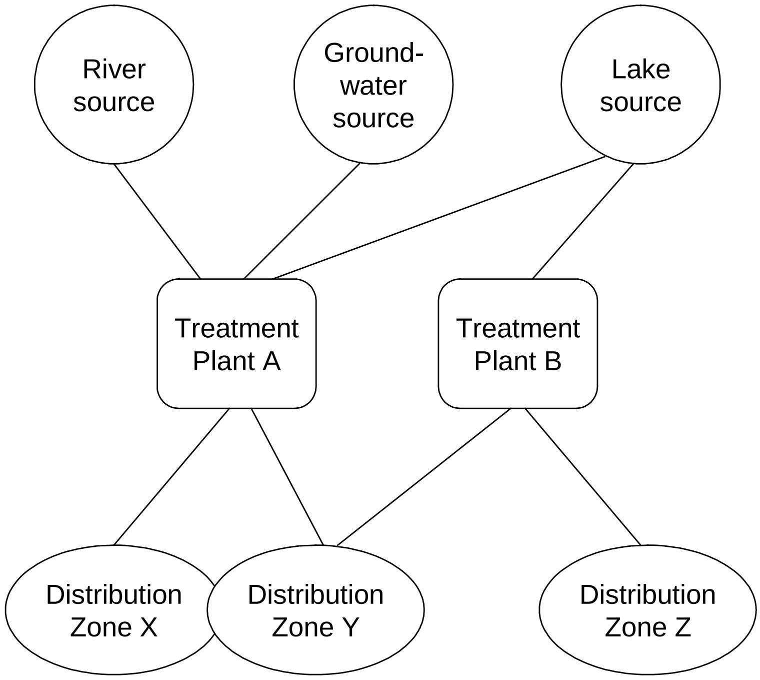
A community water supply comprises one or more of the following (see Figure 2.1):

- the source of raw water
- the treatment plant
- the distribution system.

Individual components and chemicals used in the water supply need to be appropriate, ie, should not compromise the quality of the water. New Zealand, Australian, UK, ISO and US standards should be referred to where possible. Examples include:

- List of Approved Products for Use in Public Water Supply in the United Kingdom, see http://dwi.defra.gov.uk/drinking-water-products/approved-products/soslistcurrent.pdf
- AS/NZS 4020:1999. Products for use in contact with drinking water.

Figure 2.1: Schematic diagram of a drinking-water supply system



2.1.1.1 Source water

A community water supply may abstract raw water from rainwater, surface water or groundwater sources. These are discussed in Chapters 3 and 4; Chapter 8 which describes the source water categories for *Cryptosporidium*; and Chapter 19 which focuses on small water supplies, including rainwater supplies.

Surface water is frequently contaminated by micro-organisms. Waters from shallow groundwater sources and springs are microbiologically equivalent to surface water, along with rivers, streams, lakes and reservoirs. Secure bore water is considered to be free from microbiological (bacterial and protozoal) contamination, see Chapter 3.

A water supply may have more than one source of raw water. Secondary sources may be permanent or temporary. Temporary water supplies are discussed in section 6.8 of WHO (2011). Tankered water is covered by the *Guidelines for the Safe Carriage and Delivery of Drinking-water* (MoH 2008).

2.1.1.2 The treatment plant

A treatment plant is a facility that treats raw water to make it safe and palatable for drinking. To harmonise the DWSNZ with the conventions used in the public health grading of community drinking-water supplies, the treatment plant is considered to be that part of the system where raw water becomes the drinking-water. This can range from a full-scale water treatment plant comprising chemical coagulation, sedimentation, sand filtration, pH adjustment, disinfection and fluoridation, to simply being the point in a pipeline where the water main changes from a raw water main to a drinking-water supply main. In a simple water supply, the water may be merely abstracted from a river, passed through a coarse screen and piped to town; thus the water supply acts like a diverted stream. If the raw water is chlorinated, however, it will not be considered to become drinking-water until it has been exposed to chlorine (or chlorine dioxide) for the design contact time.

A treatment plant may receive raw water from more than one source.

Water treatment and disinfection processes are discussed in Chapters 12–15.

2.1.1.3 The distribution system

Once the water leaves the water treatment plant, it enters one or more distribution zone(s) that serve the community. The DWSNZ and the Public Health Grading of drinking-water supplies define a distribution zone as:

> "the part of the water supply network within which all consumers receive drinking-water of identical quality, from the same or similar sources, with the same treatment and usually at the same pressure. It is part of the supply network that is clearly separated from other parts of the network, generally by location, but in some cases by the layout of the pipe network. For example, in a large city, the central city area may form one zone, with outlying suburbs forming separate zones, or in a small town, the system may be divided into two distinct areas. The main purpose of assigning zones is to separately grade parts of the system with distinctly different characteristics."

A distribution zone may receive water from more than one treatment plant. The distribution system may comprise more than one distribution zone. See Figure 2.1.

Distribution zones are distinguished because they may:

- be fed by a pumping station so that they are isolated from nearby zones by pressure
- be fed from a service reservoir which can markedly increase the retention time
- vary seasonally due to supplementary sources being used at peak draw-off times
- the boundaries may vary due to changes in pressure or draw-off

- vary due to the materials used in common sections of the distribution system
- receive their water from another supply by tanker that pumps the water into a storage tank
- receive their drinking-water from a water supply wholesaler via bulk mains.

The distribution zones selected for the Public Health Grading and the DWSNZ are based on water quality considerations and will not necessarily coincide with the distribution zones which the water suppliers identify for operational and management purposes. Many community drinking-water supplies comprise one distribution zone only.

The distribution system is discussed in Chapter 16.

2.1.2 Overview of management systems

There are a number of concepts and techniques that are useful for the management of water supply systems. These include:

- risk management (as outlined in section 2.2), which involves identifying, controlling and minimising the impact of uncertain events
- quality assurance (as outlined in section 2.3) which is based on controlling processes to provide consistent products that satisfy customer requirements
- quality control measures (as outlined in section 2.4), which provides the checks to demonstrate the product is complying with standards, and feedback to the adequacy of risk management
- asset management, which involves the management of assets to achieve the required levels of service.

From the time the *Drinking Water Standards for New Zealand 1995* were prepared, the emphasis of the Ministry of Health has shifted from quality assurance to risk management.

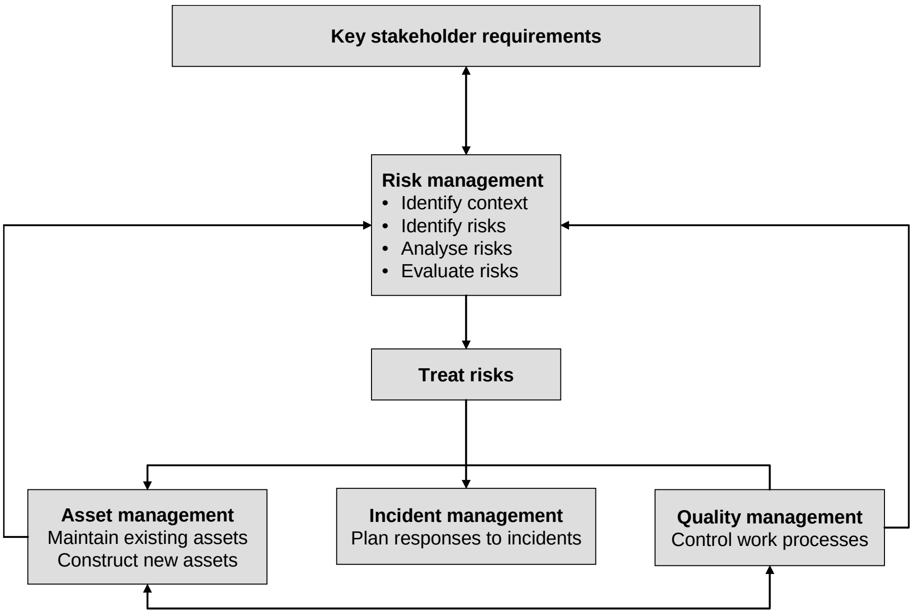
Quality assurance techniques were first devised for the control of manufacturing processes. They aim to ensure a consistently acceptable end product by understanding and controlling the processes used to produce that product. Quality assurance techniques recognise that there will be a percentage of products that do not comply with the specified requirements and concentrates on reducing this quantity to an economically acceptable level. Whilst this approach offers many benefits, it is not completely suitable for the management of water supplies, where the release of even a very small amount of contaminated water can impact on public health, and cause economic and social impacts.

Risk management on the other hand concentrates on identifying, controlling and minimising the impact of uncertain events. Like quality assurance it recognises that sometimes things will not go as planned and aims to identify the causes of these problems and early warnings that the events are starting, and put into place measures to control their impact. Emphasis is placed on developing plans that detail how to prevent events occurring and to respond to events when they do occur.

The use of risk management principles provides a greater certainty that the water being provided to the public is safe than is given by merely monitoring compliance with standards (quality control). This approach to water supply management leads water suppliers to consider what can possibly go wrong in a water supply, to pinpoint what the causes may be, and once identified, to take actions to reduce the likelihood of the event occurring.

Whilst quality assurance and risk management techniques have different emphases, they both involve similar tasks and both techniques have a place, along with asset management techniques, in the integrated management of water supply systems, as illustrated in Figure 2.2. Risk management techniques are used to identify what can go wrong and for putting in place measures to reduce these risks. Often the measures will involve controlling the everyday work processes through quality assurance techniques. In other cases measures may involve the maintenance or upgrading of assets such as treatment plants and distribution pipes, using asset management techniques to decide when and/or how to upgrade or maintain these assets. The understanding gained from the application of quality assurance and asset management to the operation, maintenance and upgrading of the water supply system will in turn provide a better understanding of the risks that can affect the system. When this is fed back into the risk assessment the whole cycle starts again.

Figure 2.2: Integrated management of water supply systems



The Australian Drinking Water Guidelines (NHMRC 2016) discuss six guiding principles for assuring safe drinking water:

1. The greatest risks to consumers of drinking water are pathogenic microorganisms. Protection of water sources and treatment are of paramount importance and must never be compromised
2. The drinking water system must have, and continuously maintain, robust multiple barriers appropriate to the level of potential contamination facing the raw water supply.

3. Any sudden or extreme change in water quality, flow or environmental conditions (eg, extreme rainfall or flooding) should arouse suspicion that drinking water might become contaminated.
4. System operators must be able to respond quickly and effectively to adverse monitoring signals.
5. System operators must maintain a personal sense of responsibility and dedication to providing consumers with safe water, and should never ignore a consumer complaint about water quality.
6. Ensuring drinking water safety and quality requires the application of a considered risk management approach.

2.2 Risk management

2.2.1 General

Risk is measured in terms of:

- likelihood, ie, what is the probability or chance that the event will occur
- consequence, ie, what harm will be caused by the event.

Risk management, therefore, places emphasis on preventing events occurring (to reduce the likelihood) and responding to events when they do occur (to reduce the consequences).

WHO (2013) states that risk perception is formed by two components: hazard and outrage. Hazard (the technical, scientific aspect) combines the probability of a certain event occurring with the severity of the outcome. Outrage (the subjective part) focuses on the situation as opposed to the extent of the risks, including the nature of the risk and the way it is managed. The main components of outrage factors are the involuntary nature of the issue, the artificial (industrial) nature of the risk, the use of cover-up or silence, attempts to engage message recipients to persuade them about the issue, the occurrence of accidents, double truths around the issue, conflicts of interest, contradictory messages and inequitable distribution of risk. It has been demonstrated that a clearer perception of the risk by the population leads to a higher effectiveness of the protective measures established by health institutions. Uncertainty also plays an important role in environmental risk assessment, management and communication. Uncertainty should be acknowledged as a central component in the management of environmental risks. It is important to consider and assess uncertainties in the risk assessment process, since not doing so leads to a distortion of study conclusions. Recognition of uncertainties allows for their further reduction in future studies and unmasking in previous cases. It can also help in the taking of political and regulatory decisions.

In the case of a water supply, an event would be something that has the potential to compromise the ability to supply safe drinking water. Examples could include:

- the water supply being contaminated by faeces and people becoming sick because of drinking contaminated water
- a truck or unbunded tank spills its chemical load upstream of the intake and people becoming sick because of drinking contaminated water
- a power failure at the pump station and people becoming sick because they do not have access to enough safe water
- an operator not taking appropriate action in response to a bad water test result and people becoming sick because of drinking contaminated water. See Water UK (2010).

The concept of the process for managing risk is shown in Figure 2.3.

Figure 2.3: The risk management process

Risk analysis

Risk analysis involves:

- identifying events that may introduce hazards (contaminants that can make you sick) into the water
- establishing the likelihood and consequence of each event – the risk
- determining the tolerability or acceptability of the risks
- identifying possible options to reduce the chances of the events occurring and/or the impact of the events should they occur
- balancing the costs and benefits of each option for achieving acceptable risk levels.

Risk reduction

Risk reduction involves implementing the measures to reduce the likelihood or consequence of the events determined in the risk analysis – a proactive step. Typical measures include:

- determining the scope/tasks of the reduction measures
- assigning responsibilities to the tasks
- determining a timeline for implementing the measures
- implementing the measures
- checking that the measures have been successful.

Examples of risk reduction measures may include additional/improved treatment processes, online monitoring, or improved training.

Readiness

Where it is not practical to completely eliminate the risk through the implementation of risk reduction measures, organisations need to be ready to deal with the risk event when it occurs – preparation for the reactive response step. This involves:

- preparing contingency plans that detail what personnel will do when a risk event occurs – measures to deal with the event itself (eg, fix the broken pipe, restore residual chlorine level) and measures to deal with the consequences of the event (eg, issue boil water notice,[1] alert medical services)
- establishing relationships and outlining the channels of responsibility and communication with key stakeholders, peer organisations, regulatory authorities, suppliers and service providers so that they are in a position to help during a risk event
- the training of staff in incident management techniques and their individual roles in managing incidents
- conducting exercises to train staff and test contingency plans.

Response

When a risk event arises organisations need to be able to respond and implement quickly and effectively the contingency plans that they have already developed in readiness – a reactive step. Therefore, organisations need to conduct team exercises regularly to practise and fine tune any response processes that they have designed and prepare robust communication systems.

[1] Chapter 6 includes an Appendix: Boil Water Notices.

Recovery

Recovery involves two stages:

- firstly, the measures taken to return operations to normal and put to rest any customer or community dissatisfaction
- secondly, the analysis of the event and carrying out debriefings, to learn from the event and put into place measures to reduce the likelihood of it recurring.

The results of the debriefing should be fed back into the risk analysis thus closing the cycle and allowing it to start again. Over time this will help organisations gain a better understanding of the risks that can affect their operations and they should become smarter at handling them.

For further reading on the topic of risk management, see Chapter 10 of WHO (2001), WQRA (2009) and NHMRC (2012).

2.2.2 Water Safety Plans (WSPs)

The Ministry of Health (MoH) introduced the concept of Public Health Risk Management Plans (PHRMPs) in 2001 for managing public health risks associated with water supplies; MoH advocated their use. The 2005 DWSNZ introduced a new section: section 10, for small water supplies. Small water supplies had the option of following the compliance criteria in sections 4, 5, 7, 8 and 9, or using section 10 which allowed a reduced monitoring regime provided water suppliers adopted a PHRMP approach. When the Health Act was amended PHRMPs were renamed Water Safety Plans (WSPs). Section 69Z of the Health Act describes the statutory requirements for WSPs.

WSPs are action plans that show how risks to public health that may arise from the drinking-water provided by the supply will be reduced. In 2012 WHO published *Water safety planning for small community water supplies step-by-step risk management guidance for drinking-water supplies in small communities*. This includes a case study, based on New Zealand publications. WHO described water safety plans as "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 water supply from catchment to consumer".

WHO (2005) discusses managing drinking-water quality from the catchment to the consumer. WHO (2007) was written to help users at national or local level to establish which chemicals in a particular setting should be given priority in developing strategies for risk management and monitoring of chemicals in drinking-water. WHO (2009) is a manual for developing WSPs. WHO (2011) was written to "increase confidence that safe water is consistently being delivered to consumers by ensuring that key elements in the WSP process are not overlooked and that the WSP remains up to date and is effective". WHO (2016a) provides a structured approach to understanding surface waters and their catchments to support the identification, assessment and prioritization of the risks, and the development of management strategies for their control.

Section 2.2.2 provides background information about the approaches that the Ministry of Health has taken. It also includes subsections on the model *Public Health Risk Management Plan Guides* (the Guides), which provide generic information that can be of assistance in the preparation of water safety plans, and a discussion of the Ministry's document *How to prepare and develop Public Health Risk Management Plans* (MoH 2001), which provides suggestions as to how WSPs can be developed from the Guides.

The Ministry has developed a *Small Drinking-water Supplies: Public Health Risk Management Kit* (MoH 2008), which is discussed in Chapter 19: management of small supplies.

WHO (2014) is a field guide that contains short explanations of the water safety planning process (including practical templates and tips) that support WSP development and implementation in small communities. They stress that a WSP covers all steps of the water supply system from the area where the source water originates all the way through to the point of water consumption. The whole system should be described as the basis for the WSP tasks which they itemise, along with tips and templates.

WHO (2015) supports the development and implementation of customised WSP auditing schemes by setting out the most important considerations and requirements, including:

- audit objectives
- audit methodology
- audit scope and depth of investigation
- audit timing and frequency
- auditor qualifications
- auditor training and certification
- establishing audit criteria
- evaluating and reporting audit findings.

The Guide includes a New Zealand case study.

More recent WHO publications on water safety plans include (see **http://www.who.int/water_sanitation_health/publications/water-safety-in-distribution-system/en/**):

- *Climate-resilient Water Safety Plans: Managing health risks associated with climate variability and change*. 92 pp. 2017.
- *Global Status Report on Water Safety Plans: A review of proactive risk assessment and risk management practices to ensure the safety of drinking-water*. Geneva. World Health Organization. Licence: CC BY-NC-SA 3.0 IGO. 44 pp. 2017.
- *Capacity Training on Urban Water Safety Planning – Training Modules*. 720 pp. 2016.
- *Water Safety in Distribution Systems*. 160 pp. 2014.

2.2.2.1 The Ministry of Health's model approach to public health risk management

The key documents of the Ministry's approach are the *Public Health Risk Management Plan Guides* (the Guides). There is no requirement for water suppliers to make use of the Guides; they may use them to whatever degree they wish.

Some terms that are used in the following sub-sections and definitions may be helpful are:

- Supply element: a physical or operational component of a water supply. Supply elements act together to determine the quantity and quality of the water received by the consumer.
- Hazard: a microbiological or chemical determinand that may cause sickness.
- Event: an incident or situation that may introduce a hazard (or hazards) into the water.
- Cause: the situation, action or inaction resulting in an event.
- Preventive measure: an action taken, or process, to reduce the likelihood of an event occurring.

2.2.2.2 WSP guides – development

To determine which Guides had to be prepared, water supplies were considered to consist of three supply stages: source, treatment and the distribution system. Within each of these stages supply elements were identified. The elements are the physical or operational components contained in each stage. They act together to determine the quantity and quality of the water received by the consumer.

Some elements, such as the process of disinfection, can be further subdivided, eg, chlorination, ozonation, etc. These were termed sub-elements. WSP Guides have been prepared for all elements and sub-elements where they existed. The contents of the Guides are discussed in section 2.2.2.3.

The most important factor influencing the form of the Guides was the need to make them generic documents, ie, generally applicable, not designed to meet the needs of a particular supply.

A number of principles acted as the basis for the development of the Guides:

a) The Guides focus on what might go wrong within a supply (ie, the events), not the microbiological or chemical contaminants (hazards) in the water or the preventive measures. This was done to avoid overlooking:
   - hazards that may not have been identified at the time the Guides were prepared
   - other events, not identified in the Guide, because of too narrow a focus on the preventive measures.

b) The Guides identify preventive measures that might not be possible to act on at present in some supplies. These are included because they are considered important and need to be noted in case future developments allow them to be put in place. Examples of this are preventive measures that cannot be implemented because water suppliers lack the legislative authority to manage their own catchments. Future changes to legislation may allow these preventive measures to be implemented.

c) The Guides have been regarded as a means of improving industry practices where this seems reasonable. As a result, some water suppliers may find that their present practices fall short of some preventive measures and corrective actions in the Guides, and they will need to review whether an improvement in the way they manage their supplies can be achieved. These situations will probably arise most frequently in relation to distribution systems.

d) Events with various levels of risk have been included in each Guide. No attempt has been made to omit events because they were considered to be too low a risk. Each water supplier has to determine the importance of each event for their particular situation; the Guides only indicate what should be considered.

e) The Guides only provide generalised estimates of the levels of risk associated with each supply element. To obtain a fuller assessment of the risk associated with each event, water suppliers have to analyse the risks based on the circumstances in their supplies. The Guides do, however, contain two features that give an indication of the typical importance of events for public health:
   - an estimate of the level of risk associated with each event (evaluated on what might be expected for most supplies)
   - a risk summary, in which the event considered to present the greatest risk to public health for a particular supply element is identified, along with the most important preventive measures for this event.

2.2.2.3 WSP guides – content

The Guides are the building blocks from which water safety plans can be prepared. They contain the following sections and information:

1 Introduction: The introduction outlines the topics covered by the Guide. It also sets out possible events that can be associated with the supply element, the possible public health consequences of each event, and how the particular element can influence, or be influenced by, other supply elements. This last item is important, because it provides the operator with guidance on how the risks associated with one element may be modified by another.

2 Risk summary: The risk summary's purpose is to summarise the key information contained within the Guide. It is included for the supplier that may have limited understanding of drinking-water quality management. Even if the full information table later in the Guide cannot be understood, the risk summary provides, in simplified form, the most important information.

3 Risk information table: This table contains the detailed information that can be used in managing risks associated with the supply element. The table is divided into sections, each of which deals with a particular event. The heading of each section states the event, the hazard(s) that may be introduced as a result of the event, and provides a guide to the typical level of risk associated with the event, more lately referred to as critical control points. The events contained in the tables are potential events. They are listed to alert water supplies to events that may occur; their appearance in the table does not mean that they are all relevant to a particular supply. The supplier has to decide this for his/her own supply.

There are some deviations from this. There are some instances where micro-organisms are the hazard, but they may not be pathogens of faecal origin. For example, where sediment in part of the system is stirred up (eg, Event P2.2), faecal pathogens are not the concern. The organisms introduced into the water may be opportunistic pathogens. These organisms may be part of the normal microflora of the body, but under certain conditions cause disease in compromised individuals (Geldreich 1996).

Because the actual risks presented by a particular event will depend on the situation existing in the supply; an accurate indication of the level of risk cannot be provided in a generic document. The levels of risk given provide some guidance for those who feel unable to estimate more accurately the risks for their supply. Section 2.2.2.6 offers more detail about how to estimate a qualitative level of risk for an event.

Listed within each section of the risk information tables (ie, concerned with one event) are:

- possible causes of the event
- preventive measures that can be taken to reduce the likelihood of the event arising from that particular cause
- checks that can be made to determine whether the preventive measures are working
- signs from the checks that show when preventive measures have failed and action needs to be taken
- corrective actions that need to be taken if the event occurs despite the preventive measures in place.

Preventive measures and corrective actions are distinguished by the way in which they deal with the two aspects of risk. Preventive measures are intended to reduce the likelihood of an event; corrective actions aim to reduce the consequences of the event if it occurs. In some instances, corrective actions set up preventive measures that should have been in place already.

The suggested checks are to determine when an event has occurred and a preventive measure has not worked. Trouble-shooting may be assisted in some instances by checks that are specific to certain preventive measures and the causes they are designed to control. There are other checks, however, that are not so specific. These provide limited help in identifying the cause of an event. For example, free available chlorine (FAC) measurements are checks common to all causes that may result in the FAC concentration being too low during chlorination. A low FAC result (a critical control point) therefore indicates that an event has occurred, and that a preventive measure has failed, but does not pinpoint what caused the problem.

The supply of undisinfected water by a water supplier in Melbourne caused by a disinfection plant failure was identified as one of the significant risks, or critical control points (CCPs), in both the wholesaler's and in the retailer's WSPs. Significant operational improvements were therefore made, including continuous monitoring of key indicators of water treatment (for example chlorine, turbidity, filter head loss); continuous review of CCP performance, including treatment plant failures; operator training; internal, external and regulatory audits; and well-established programmes of water treatment plant maintenance. As a result, a significant reduction in critical limit breaches has been achieved since 1999, including fewer disinfection plant failures. As disinfection plant failure triggers a declaration of an incident, operational expenditure on the order of A$10,000-50 000 per incident has been avoided. Typical examples of costs avoided include mobilisation of an incident management team, field work such as water mains cleaning (flushing, air scouring, swabbing), spot chlorination of water storages, use of bottled water, use of water tankers as an alternative water supply, additional water quality sampling and laboratory testing, and customer and media communications, not to mention loss of confidence by the public. From WHO (2018).

4 Contingency plans: Contingency plans have been prepared for events resulting in either serious microbial contamination of the water, or substantial chemical contamination that will have acute consequences. The concentrations at which chemical hazards generally occur are low enough that their consequences are long-term. The contingency plans contain information to assist in deciding when a contingency plan is needed, and the actions that should be taken.

Contingency plans are distinguished from corrective actions on the basis of the level of risk they are intended to manage. For example, the detection of low levels of a faecal indicator in the treated water requires a corrective action, but not the implementation of a contingency plan. The detection of high levels of faecal contamination, or evidence of widespread sickness that is likely to be of water-borne origin signals the need to implement a contingency plan. The need for the implementation of a contingency plan may arise from the failure of corrective actions to reduce a hazard in the water to an acceptable level.

5 Performance assessment: This section of the Guide lists checks that can be made to establish how well the plan is working for the particular element in question, and how frequently the checks need to be made. Many of the checks are the same as those noted in the risk information table. Guidance is also provided on what needs to be done with the results of checks, particularly with respect to their review, and the need to use this information in the updating of the plan.

The Guides may not have identified all possible events, their causes or appropriate preventive measures. It is therefore important that, when a WSP is prepared, the water supplier remains alert to the possibility that events not listed may also occur, and does not rely solely on the Guides.

2.2.2.4 The preparation of WSPs

Guidance on the preparation and implementation of WSPs is provided in the Ministry of Health's publication *How to Prepare and Develop Public Health Risk Management Plans*. The publication serves a number of functions by:

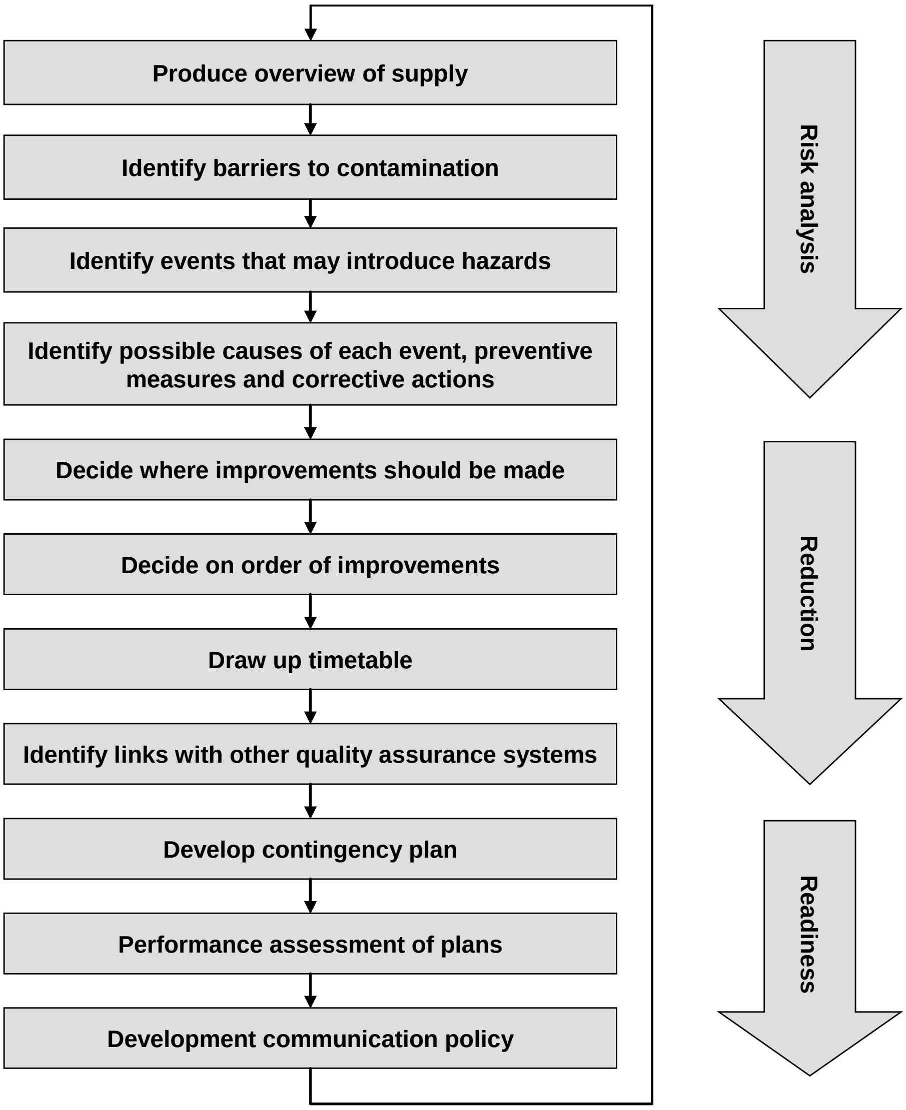
- setting out which Guides are available
- explaining in general what they contain, and the terminology used
- offering direction in the use of the Guides in preparing WSPs
- offering direction for the use of the plans once they have been prepared.

A suggested approach to the development of WSPs is set out in Figure 1 of the publication. It outlines a series of steps that should be taken in preparing plans, provides some detail as to how to carry out the step, and indicates what should come out of the step for addition to the supply's WSP. The steps are summarised in Figure 2.4 and outlined below.

It is preferable that water suppliers prepare their own WSPs, because during the process, they will become more aware of each step involved in running the supply, identify the critical points, and will therefore consider the risks, monitoring, improvements and training needs associated with each step. If it is considered necessary to use consultants, the water supplier must be closely involved in the preparation of the WSP. It is recommended that the WSP makes frequent reference to all relevant operations manuals.

WRF (2016) developed an approach for identifying potential sources of contamination upstream of drinking water intakes, particularly from aboveground storage tanks. The project was designed to help drinking water utilities follow the AWWA Standard G300 (*American National Standard for Source Water Protection)* and related guidance. The work also contributes to emergency preparedness, response, and health and safety management. They developed an eleven-step method to cover the process from delineation of upstream contributing areas and zones of concern, through data mining, contaminant research, aerial image analysis, and SWP planning and implementation. The challenges and benefits of maintaining this type of database are discussed in the report.

Figure 2.4: Suggested approach for the development of WSPs



Risk assessment

Step 1: Produce an overview of the supply and decide which WSP Guides are needed
Contribution to the WSP: a flow diagram of the supply

The water supplier needs to identify all the elements in their supply. Without doing this all possible events that may lead to hazards being in the water cannot be identified. The step also serves to help the supplier determine which Guides will be required for preparation of the plan. The task is best accomplished by methodically working through the supply from the catchment or recharge zone, to the consumer's property and identifying all activities, processes, or physical components that may influence the quantity or quality of the water.

Although the term supply is used in the Guides, and in this section of the Guidelines, the WSP is being prepared to protect the consumers in a particular distribution zone. A neighbouring distribution zone may be subject to different events, so its WSP will need to be different.

Where more than one plant and/or more than one source provides water for a distribution zone, the flow diagram prepared in this step must include all supply elements that could influence the quality of the water reaching the distribution zone of interest.

How a water supplier is to deal with more than one supply/distribution zone in determining the priority of resource allocations is described in Step 6.

Step 2: Identify the barriers to contamination
Contribution to the WSP: checklist of barriers present

Between the source water catchment or recharge zone and the consumer's property, various elements of a water supply act as barriers to the entry of contaminants. Each barrier contributes to the safety of the supply, but it is generally recognised that the greatest protection to water quality and public health is achieved by ensuring that four fundamental barriers are in place. These four barriers must achieve the following:

1 prevention of contaminants entering the raw water of the supply
2 removal of particles from the water
3 inactivation of micro-organisms in the water
4 maintenance of the quality of the water during distribution.

Step 2 is very important in the development of the WSP because the absence of a barrier may not necessarily become evident during other steps in the preparation of the plan. A water supplier needs to know when any of these barriers is missing in their supply, because the maximum level of public health protection, especially with regard to pathogens, cannot otherwise be achieved. Supply elements that may contribute to each type of barrier are listed in Table 2.1.

Table 2.1: Supply elements contributing to the four main barriers to bacterial contaminants

Barriers to …	Actions or supply elements contributing to these barriers
Stop contamination of raw waters	Use of secure groundwaters Abstraction point positioned and constructed to avoid contamination Source protected from contamination Actions to avoid contamination of roof catchments, and contaminants being washed from roofs
Remove particles from the water	Coagulation/flocculation/clarification Dissolved air filtration Filtration
Kill germs in the water	Disinfection (chlorine, chlorine dioxide, ozone, UV light)
Preventing recontamination after treatment	Measures to stop contamination of storage tanks Maintenance of a disinfecting residual Actions taken to avoid contamination during distribution Installation of backflow preventers where necessary

Step 3: Use the Guides to identify events that may introduce hazards into the water
Contribution to the WSP: Feeds into the supply's risk information table

This is the first of two steps that are the basis for producing the supply's customised risk information table. The Guides have been prepared with the aim of identifying all possible events associated with a particular supply element. It is possible that some events have been omitted, or that events that are irrelevant to a particular supply have been included. For these reasons, a water supplier needs to work through the events listed in the Guide, select those that are relevant for their customised risk information table, and add other events of concern that have not been considered.

Risk management

Step 4: Use the Guides to identify:

- causes
- preventive measures
- corrective actions

Contribution to the WSP: Feeds into the supply's risk information table

This is the second step contributing to the preparation of the customised risk information table. Having identified the events relevant to their supply, the water supplier now needs to go through the same process of identifying the causes, preventive measures, checks on preventive measures and corrective actions that are relevant. The preventive measures, checks and corrective actions that appear in their risk information table ought to include all that should be in place, not simply those that are actually in place.

Section 2.2.2.2 noted that some preventive measures have been included that it might not be possible to act on at present in some supplies. Preventive measures of this type should be included in the supply's risk management plan with a flag that the measure cannot be implemented, and a note made of the reason. The supply's assessor will verify this during the assessment of the plan. The inclusion of these measures will serve as a reminder of the actions that need to be taken when their implementation becomes practicable.

Step 5: Decide where improvements should be made in the supply to better protect public health
Contribution to the WSP: Feeds into the supply's improvement schedule

This is the first of three steps that are the basis for preparing the improvement schedule. The purpose of this schedule is to list any of the four main barriers, preventive measures, checks or corrective actions that are missing from a supply.

From Step 2 it will be possible to identify which, if any, of the four barriers are missing from the supply. A secure bore water has met the first three barriers with respect to microbiological contamination. In the absence of dissolved chemicals of public health significance, prevention of contaminants entering the water after it is abstracted from the ground is then the only concern.

The preventive measures, checks and corrective actions that should be in place will be contained in the risk information table as the result of Step 4. These now need to be compared with what is actually in place in the supply. Identifying which preventive measures and checks are not in place, but need to be, should be straightforward. The situation is different for corrective actions however. These are actions that will not need to be taken until something goes wrong with the preventive measures. Consequently, the main concern with the corrective actions is to make sure that they are listed in the customised risk information table. In the event of something going wrong, the person responsible for the supply can then refer to the table for guidance on the appropriate action.

Step 6: Decide on the order in which improvements need to be made
Contribution to the WSP: Feeds into the supply's improvement schedule

In this step priorities must be assigned to the improvements identified in Step 5. The most important factors to be taken into account when making these decisions are: public health, availability of resources, and the ease with which the improvement can be made.

The suggested approach is first to produce a table that ranks the preventive measures that need to be put in place in the order of the level of public health risk of the event they are intended to stop. Preventive measures associated with high-risk events should be given high priority for attention.

The Guides provide some help in obtaining estimates of public health risk:

- the risk summary in each guide indicates which events are considered to present the highest public health risk for the particular supply element, as well as the preventive measures considered most important in controlling these events
- the risk information table provides estimates of the level of risk for each event. The limitations of these typical values were discussed in section 2.2.2.2.

Where water suppliers wish to obtain an estimate of risk that is more tailored to their supply, Appendix 2 of the Ministry's guide to the preparation of PHRMPs (MoH 2001) describes how the level of risk can be estimated from its two contributing factors of consequence and likelihood. This is described more fully in section 2.2.2.6.

Once an order of importance based on public health has been determined, the water supplier needs to consider how resources (financial and otherwise) and the ease of carrying out improvements may modify this ranking. High priority should be given to improvements that can be easily made at little cost. The improvement schedule from the WSP should contribute to the preparation of the supplier's asset management plan.

The WSP should contain information giving the reasons for the final order assigned to the improvements; the assessor will seek this. The documentation should include:

- any information used to assess the likelihood of an event, if the supplier carried out their own risk estimation
- the basis for deciding on the priority of improvements when the qualitative estimated risk levels were the same
- information on costs of improvements

- links to the supply's asset management plan
- a note on the ease of implementation where this influenced the ranking
- any other factors, eg, political, that have been important in making the ranking decision.

The detail provided should be proportional to the size of the supply in question: small supplies require a minimal amount of detail, and large supplies considerably more.

Water suppliers with more than one supply face a more complex situation. When evaluating the importance to public health of improvements required in a single supply, the population is a common factor and does not have to be considered. When a supplier has responsibility for more than one supply/distribution zone, however, account needs to be taken of the population when comparing risk to public health of events in different supplies. The population of a supply determines the number of people who may get sick, and may also influence political considerations.

A possible approach to determining the order in which improvements should be made, or resources allocated, to a number of supplies is as follows:

1. Prepare a WSP for each supply/distribution zone. The improvements schedule should not take account of resources, as account is taken of these later in the process. An overall schedule for improvements for all the supplies/distribution zones will also have to be prepared as part of the following process.
2. On the basis of the information in each plan estimate the overall level of public health risk for each supply individually.
3. Using the level of public health risk for each supply found from the previous step (point 2) and taking account of the population, rank the supplies/distribution zones in order of their public health risk. Supplies with large populations and a high public health risk will be at the top of this list, and small supplies with a low public health risk at the bottom. Judgement will be required when determining the relative rankings where the situations are not so extreme, eg, small supplies with high public health risk, and large supplies with relatively low public health risk.
4. Having identified the supply with the greatest need for improvement from point 3, allocate funding to the highest priority improvement needed for this supply from its improvements schedule.
5. Return to point 2 and re-evaluate the overall level of public health risk assuming that the improvement in point 4 has been made and is working properly, ie, the likelihood of a particular event has been reduced. This process should be repeated until available resources are exhausted, or there are no more improvements to be made. By the end of the process, a list to provide the basis for an improvements schedule for all supplies/ distribution zones will have been produced.

Step 7: Draw up a timetable for making the improvements
Contribution to the WSP: Feeds into the supply's improvement schedule

The final step in developing the improvement schedule is to assign a completion date and responsibility to each improvement.

Step 8: Identify links to other quality assurance systems
Contribution to the WSP: Note of other quality assurance systems in place

A WSP is one of a number of quality assurance systems a water supplier may have in place. Other systems may include monitoring and maintenance programmes and ISO 9000/14000 series systems. Maintenance schedules and monitoring programmes are suggested in many of the Guides. These, and other relevant programmes not mentioned in the Guides, should be referenced in the plan once they are implemented.

A properly developed ISO quality assurance system should aim to achieve the same goal as the WSPs, namely the protection of public health. Water suppliers with ISO systems in place should check to ensure that the ISO system provides a degree of detail for managing public health risk similar to that expected in the WSPs. If it does not, a WSP needs to be developed and linked into the ISO system to cover those aspects of management not properly dealt with by it.

A supply's WSP aims to identify possible sources of hazards that may enter the supply and the likely effectiveness of barriers to these hazards. This type of information cannot provide a supplier with information about the actual hazards present, nor their concentrations. To improve the assessment of actual risk to public health, monitoring, additional to that already undertaken for compliance or process control, is of value. This additional monitoring will identify which hazards are affecting water quality, their concentration and how variable their concentrations are. The information will help in deciding on appropriate preventive measures. Monitoring being undertaken for this purpose should also be referenced in the plan.

Step 9: Prepare contingency plans
Contribution to the WSP: Contingency plans for each supply element

Suggested contingency plans are provided in each Guide for the supply element discussed. The purpose of having contingency plans is to ensure that there is available a set of steps, thought out in advance, for reacting rapidly to situations that may pose a major threat to the health of a community through their water supply. A supply's WSP, and its contingency plans in particular, therefore need to be readily accessible to those who are likely to have to make supply management decisions in such an emergency.

Suppliers should determine which of the contingency plans in the Guides are relevant to their supply, and include additional ones if a potential situation of high risk is not covered by the existing contingency plans. The contingency plans in the Guides provide a template for the preparation of any new plans needed.

Contingency plans have been prepared to cover situations in which normal corrective actions have failed to stop hazards entering the distribution zone. They are intended to deal with circumstances in which high levels of pathogens have entered the distribution zone, or when there is acute risk from chemical contaminants. Acute chemical risks may arise from such incidents as chemical spills, volcanic eruptions, or flooding, which may deposit high concentrations of chemical contaminants into a source water.

Drought is normally associated with water shortage, but it can also impact on water quality. Cyanobacteria may become more abundant (eg, as occurred in Kaitaia in the 2009/10 summer), domestic sewage can become stronger with a possible reduction in effluent quality followed by reduced dilution in the receiving water. Ash and subsequent runoff after forest fires overseas have closed water treatment plants. Prolonged drought can cause groundwater levels to fall, increasing the risk of saline intrusion; CDC (2010). DWI (2012) discusses health impacts related to extreme event water shortages. UK Government policy is for emergency plans to go beyond the routine operational events and prepare for events which may cut off water to a large number of consumers for over 72 hours and may involve more than one water supply or company. It also needs to be taken into account how the extreme event will affect logistics of distribution of alternate supplies, the health of the population without a water supply, power, sanitation and how these periods will differ from routine operational events. Extreme events affect health beyond drinking water and this is to be taken into account when planning the response and recovery.

Step 10: Prepare instructions for performance assessment of the plan
Contribution to the WSP: Set of instructions for review of the performance of the WSP

This step in the preparation of a supply's WSP sets down a procedure for the review, and where necessary, updating of the plan. The need to update a plan may arise because of:

- a change in the circumstances of a water supply
- the identification of possible new events and their causes
- the discovery that one or more preventive measures or corrective actions are unsatisfactory
- a contingency plan has failed when implemented.

Any one of these reasons leads to the need to modify the plan to minimise its weaknesses.

The WSP performance assessment section of the Guides can be used as the basis for preparing instructions for reviewing the operation of the overall WSP for the supply. In addition to the components of the review noted in the Guides, the review instructions should include the need to:

- note the frequency at which the plan should be reviewed
- record any events that have occurred since the last review, and the actions taken as a result of the event. These actions may include improvements to preventive measures, the introduction of additional preventive measures, corrective actions, and new monitoring or maintenance programmes
- record changes, additions or deletions that have been made to supply elements
- re-evaluate the improvement schedule. Changes occurring between reviews may require a revision of the relative importance of the improvements needed, and consequently a reordering of the schedule.

Step 11: Decide on communication policy and needs
Contribution to the WSP: Set of instructions for reporting

The communication section of the plan should identify and record the people to whom reports concerning the management of risk to the supply should be made, what information these reports should contain and how often they should be made.

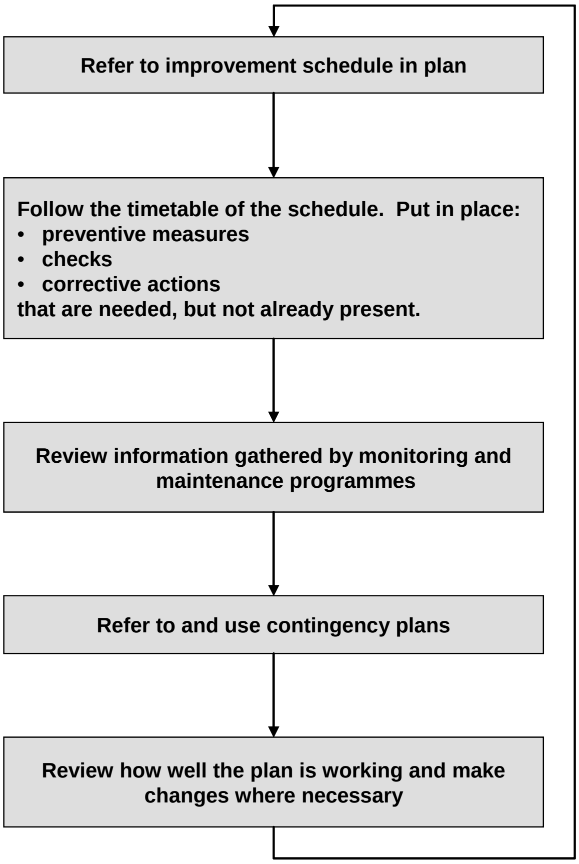
The people who need to receive reports will depend on the management/ownership structure of the supply. For example, a school may be required to report to its board of trustees and a municipal water supply manager to his or her managers, the local authority councillors, and the ratepayers.

The nature of the material reported, and the language used, need to be appropriate for the recipient(s) of the report. Thought should also be given to the way in which recipients may perceive risk and how this may need to influence the wording of the report. Perceptions of risk can vary widely depending on such things as the assumptions, concepts and needs of the stakeholders.

2.2.2.5 The implementation of water safety plans

Figure 2 in the Ministry of Health's *How to Prepare and Develop PHRMPs* publication describes what should be done with the WSP once it has been prepared. This diagram is summarised in Figure 2.5.

Figure 2.5: Process for the implementation of WSPs



Step 1: Refer to the improvement schedule.

Step 2: Follow the timetable in the schedule for making improvements.

By following the improvement schedule the water supplier should be able to:

- determine which capital works need to be undertaken and when
- determine whether any new plant is scheduled for installation and when
- put in place monitoring programmes. These should state:
  - what is being monitored
  - when samples are to be taken
  - where samples are to be taken
  - who will take the samples
  - which laboratory is to be used, or whether the measurement will be carried out by works or field staff
  - what is to happen to the results
- put in place maintenance programmes. These should state:
  - what is to be checked and maintained
  - how often checks are to be made
  - who is to make the checks
  - what is to happen to the check results
- put in place staff training programmes. These should state:
  - the purpose of the training
  - which staff are to be trained
  - how often refresher courses are needed.

Step 3: Review information gathered by monitoring and maintenance programmes.

The WSP should record how frequently information from monitoring and maintenance programmes should be reviewed, by whom, and to whom they should report in the event of something of concern being spotted.

Reviews of this nature are important in helping staff become familiar with levels of determinands, or conditions, that are normal and satisfactory, and those that are not. These reviews and alertness to changes, or the occasional result of concern, may provide signs of possible future problems. Identification of problems at an early stage may allow remedial actions to be taken before a significant threat to public health develops.

All supply staff have a responsibility for ensuring that good quality water reaches the consumer. Irrespective of the job a staff member has, if they become aware of a problem this information must be passed to their manager as soon as possible.

Step 4: Refer to and use the contingency plans if necessary.

Unlike the other steps in this sequence, contingency plans will not be used on a regular basis. When a contingency plan has to be used, the actions that need to be taken depend on such things as the type of hazard that is in the water, its likely concentration, and how far it has travelled into the distribution system. Consultation with the Medical Officer of Health may be necessary in assessing the seriousness of the event and what actions need to be taken.

As with other aspects of the WSP, it is important to discover why it became necessary to use the contingency plan, and any shortcomings of the contingency plan itself. Both sets of information can be used to modify and improve the plan.

Step 5: Review the operation and performance of the Plan.

This is discussed in step 10 in section 2.2.2.4.

Step 6: Return to step 1.

The series of steps outlined above need to follow a regular basis. This ensures that:

- the need for improvements to the supply are addressed regularly
- the Improvement Schedule is updated to take account of improvements
- the plan is modified and improved as experience shows where there are weaknesses.

As time goes on, the degree of modification required should diminish as the system becomes more refined, although major changes to the supply may require the re-identification of events, causes, preventive measures etc.

For the plan to be of value it must be used, and this is more likely to happen if it is kept current and can be used by the water supply manager as a guide to the use of resources.

2.2.2.6 Risk analysis

Risk analysis is performed to separate minor risks from major risks, and to provide information that will help in the evaluation and treatment of risks. Identification of the level of risk associated with a particular event assists in establishing the priority that should be given to putting in place preventive measures to reduce the likelihood of the event occurring.

Risk analysis can be undertaken at various levels of refinement: qualitative, semi-quantitative, quantitative, or a combination of these depending on the circumstances. Which is used will depend on the information available. Unless the information on which the analysis is based is very reliable, a set of numbers produced by quantitative calculations may give a false sense of reliability to the analysis. Should quantitative analysis be undertaken, it is advisable to carry out a sensitivity analysis to determine how the results vary as the individual assumptions made in the calculation are varied. This will show the reliability of the calculated risks.

Risk is measured in terms of consequences and likelihood (AS/NZS 2004). Thus, the level of risk of an event that has a high probability of occurring and which may lead to severe illness and death is very high. An event that may occur very intermittently, and with very little effect on public health has a low level of risk associated with it.

To evaluate the level of risk associated with an event, an estimate of how frequently such an event is likely to occur, and an appreciation of the effects on public health of the event, if it were to occur, is needed. Where sufficient data are available it may be possible to calculate the probability of the event occurring and the severity of its consequences. Situations where there are sufficient data to carry out such calculations for drinking-water supplies are rare. The water supplier therefore needs to rely on qualitative estimates of likelihood and consequence.

Assistance in evaluating consequence can be gained from understanding the factors that contribute to it. These include the:

- number of people that are exposed to the hazard(s); the greater the number of people exposed, the more severe the consequences
- nature of the hazard and its likely effect on health, which requires consideration of its concentration in the water, eg, the effects of elevated levels of algal toxins in the water, are much more severe than the presence of an organism that may lead to mild diarrhoea
- duration of exposure to the hazard(s); longer exposures may increase the severity of the health effects and increase the number of people suffering these effects.

For most events the water supplier is unlikely to have values for most of these factors. Apart from the population, a broad classification of the hazard, ie, whether it is to be microbiological or chemical may be the only guide to the severity of the consequences. The likelihood factor may therefore best assist the water supplier in estimating the level of risk for the event. Sources of information that can be of value in doing this are:

- past records
- the water supplier's own experience
- the experience and practice of the water supply industry as a whole
- published research
- the opinions of specialists and other experts.

The best guidance water suppliers have for estimating the likelihood of an event is from their own records and staff experience. The international literature may occasionally make comments about the frequency at which certain events occur. These do provide some guidance, but they may be an average value, or derived from a single supply, neither of which will necessarily provide a reasonable estimate of the frequency for the supply in question.

Appendix E of AS/NZS 4360:2004 contains an example of how qualitative levels of risk can be derived from qualitative estimates of consequence and likelihood. The tables for consequence and likelihood used in this example can be modified to provide descriptions that are more suited to water supplies. The following are suggested alternatives. For a given water supply, where the population is fixed, the descriptors for consequence may be better linked to the percentage of the population affected and the nature of the effect, eg, mild gastrointestinal upset, severe diarrhoea, etc.

Likelihood scale

Likelihood ranking	Description
Rare	May occur only in exceptional circumstances
Unlikely	Could occur
Possible	Might occur at some time
Likely	Will probably occur
Almost certain	Is expected to occur in most circumstances

Consequence scale

Consequence ranking	Description
Insignificant	Insignificant
Minor	Minor impact for small population
Moderate	Minor impact for big population
Major	Major impact for small population
Catastrophic	Major impact for big population

This gives the following estimates of risk, ISO 31000 (2009):

Likelihood	Consequences				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost certain	Medium	High	High	Very high	Very high
Likely	Medium	Medium	High	High	Very high
Possible	Low	Medium	Medium	High	High
Unlikely	Low	Low	Medium	Medium	High
Rare	Low	Low	Low	Medium	Medium

Scales of likelihood and consequence, and a risk matrix, which are more related to use in water supply than these more general tables are given in Tables 4.1 and 4.2 of the WHO *Guidelines for Drinking-water Quality* (WHO 2017).

2.2.3 Contingency planning

Water supply authorities should identify and assess any local conditions that may threaten the integrity of their system (refer section 2.2.2.2). It is essential that water suppliers develop contingency plans to be invoked in the eventuality that an emergency arises. These plans should consider:

- potential natural disasters (such as earthquakes,[2] volcanic eruptions, algal blooms, droughts and floods)
- accidents (spills in the catchment or recharge area)
- areas with potential backflow problems (including ones with fluctuating or low pressures)
- damage to the electrical supply
- damage to intakes, treatment plant and distribution systems
- human actions (strikes, vandalism, and sabotage).

Contingency planning should establish a series of steps and procedures for dealing with emergencies. The plans should specify responsibilities clearly in the water supply authority and with outside authorities for co-ordinating the response. This should include a communications plan to alert and inform users of the supply, plans for providing and distributing emergency supplies of water, and liaison with the Medical Officer of Health or other designated officer of the Ministry of Health. These plans should be developed in liaison with civil defence personnel. Contact with civil defence should be maintained and the plans updated.

The contingency plans should also cover:

- assignation of responsibilities
- priorities for dealing with multiple problems
- investigation of all probable causes of the emergency
- an assessment of the public health risk arising from the emergency
- an epidemiological investigation if deemed appropriate by the Medical Officer of Health (if a causal relationship between the water supply and illness is suspected but not obvious)
- action required to mitigate any public health risks which may have been revealed by the emergency (this may include initiating legal proceedings if negligence can be proved)
- advising and liaising with the Medical Officer of Health.

Occasional emergency exercises will help the public develop confidence in their water supply at the same time as the water supplier and cooperating parties learn how to cope.

Chapter 7 of WHO (2003) addresses emergency planning and response issues in water supplies. WHO (2011a) provides a range of technical notes covering emergencies.

[2] 37 papers were presented at the 10th JWWA/WRF/CTWWA Water System Seismic Conference in October 2017 in Taiwan. Available at **http://www.waterrf.org/PublicReportLibrary/WSSC10Proceedings.pdf**

2.2.4 Response to incidents

One of the key measures for success for a risk management system is how well an organisation responds to a risk event. Even with the best risk management system in place things will go wrong and organisations need to respond. In fact responding to a number of small events can be positive as it can help organisations identify areas that need to be improved in order to prevent larger, more serious events from occurring. Risk events have a number of characteristics including:

- they can get worse
- they can have wide ranging impacts
- their effects can be ongoing.

For example, heavy rain may initially cause flooding and resources could be focused on protecting habitable floors and maintaining road networks. However, if the heavy rain and flooding starts to contaminate the water being received at the treatment plant there may be a risk to public health from drinking water and boiled water notices may need to be issued. The incident is now far worse than initially thought, the communication needs are a lot greater, the impacts may now affect a whole community, it may take days to rectify the situation and the ongoing investigations as to why the event occurred may take several months.

Organisations therefore need systems, communication and responsibility networks and trained staff to be able to recognise and respond to the changing circumstances that occur in an event and implement the contingency plans that should have already been developed. Risk communication is discussed thoughtfully in Chapter 14 of WHO (2001). Water UK (2010a) has prepared a Technical Guidance Note to help water suppliers prepare. Risk communication is any purposeful exchange of information about risks between interested parties. More specifically, risk communication is the act of conveying or transmitting information between parties about a range of areas including:

- levels of health or environmental risks
- the significance or meaning of health or environmental risks
- decisions, actions or policies aimed at managing or controlling health or environmental risks.

Interested parties include government agencies, corporations and industry groups, unions, the media, scientists, professional organisations, interested groups, and individual citizens.

2.2.4.1 Incident levels

As risk events can very quickly escalate, become far more complicated and their effects felt more widespread, organisations often develop a system of incident levels. At the lowest level, eg, minor flooding, the situation may be handled by normal work crews, but with management and call centres informed to the extent of flooding. As the situation worsens a higher level may be triggered with more senior staff and specialist staff called in to undertake tasks such as investigating the water catchment. An even higher level may be triggered if it is likely that the water supply may be contaminated and outside agencies such as Ministry of Health and Civil Defence informed. On a larger scale, the USEPA has begun to address issues related to terrorism (USEPA 2004).

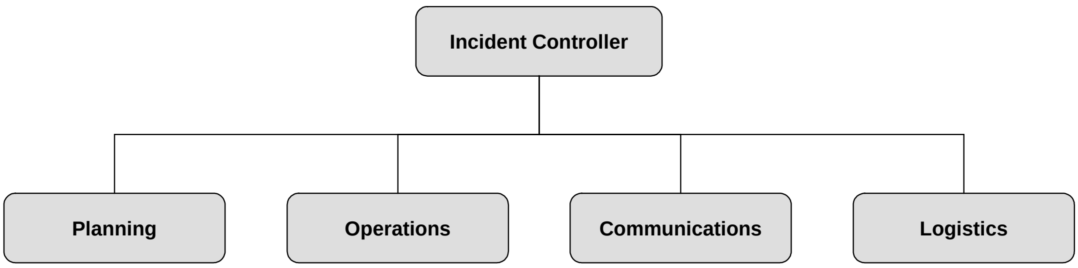
2.2.4.2 Organisation

Initially when an event occurs, the focus is often on putting the immediate situation right. However, as the event develops and escalates there needs to be increased focus on planning, communication and logistics. People need to be thinking about what is going to happen in one hour, four hours, the next day and the next week, and they need to start to put in place plans for dealing with these situations. Key people need to be communicating with the public, press and health authorities. Yet others will need to be addressing logistical issues such as organising emergency staff for the next shift, and the materials and equipment required to rectify the situation. If these areas are not addressed then the immediate situation may be fixed but the risk to public health may remain. For example in the situation discussed at the beginning of this section, if the contaminated supply to the treatment plant is isolated, but boiled water notices are not communicated to the whole community, then the public will be unaware of the potential risks and may continue to drink contaminated water.

Some organisations are therefore using the Coordinated Incident Management Response System (CIMS) as shown in Figure 2.6 to structure their teams that respond to incidents. Under the CIMS structure an Incident Controller is assigned who has overall responsibility for managing the incident. Reporting to the Incident Controller are personnel who are responsible for operations, planning, communications and logistics. Advantages of CIMS are:

- it provides clearly defined roles and responsibilities
- it compartmentalises thinking, so personnel only have to think about their particular tasks rather than trying to tackle the whole incident and miss critical issues in the process
- it provides common management structure and terminology with emergency organisations such as the Fire Service and Civil Defence.

Figure 2.6: Organisation of incident management teams



2.2.5 Debriefings

Debriefings should be conducted after all incidents and exercises. Their purpose is to use the experiences and lessons learned during the incident or exercise to make improvements, so that further incidents can either be prevented from recurring or managed more effectively. Debriefings should not be seen as a blame laying exercise; rather they should be seen as a positive step for improving the organisation's risk management.

Debriefings should involve all participants in the incident or exercise including contractors, service providers, affected parties and regulatory agencies.

The debriefing process involves:

- description of the events: involves describing the incident in detail, listing the names of the people involved, the sequence of events, the impacts of the incident and any relevant information. At this stage it is important that only the facts are recorded and assumptions are not made
- corrective action: the immediate actions taken to fix the problem are described and the people and organisations informed of the incident are noted
- immediate post incident debriefing: the views of the participants immediately after the incident are recorded. This information may be subjective and may be just one person's view, but it gives a basis for further investigation during the structured debriefing
- structured debriefing: a root cause analysis is conducted. This involves looking at each event and asking why it happened? The question continues to be asked until the team has drilled down to the root causes of the incident. The analysis considers:
  - the physical causes of the incident
  - resources, eg, equipment
  - available information, both before and during the incident
  - human resources, eg, availability of resources and training
  - communication, both before and during the incident
  - planning and procedures, both to avoid the incident and to respond to the incident
  - processes, eg, were the plans and procedures that are in place followed
  - leadership
- preventive actions: following the debriefing, the actions required to prevent a recurrence or to improve the effectiveness of the responses are identified. Staff are allocated responsibility for actioning these items and a timeline is set.

2.2.6 Sanitary surveys

The expression 'sanitary survey' is used internationally to cover a wide range of activities. The following terminology has been used in the DWSNZ:

a) catchment assessment: assessing what may affect the raw water quality
b) sanitary inspection: inspecting the whole drinking-water supply
c) bore head protection: inspecting bore heads to ensure they provide adequate sanitary protection
d) protozoal risk categorisation: considering the catchment in terms of its protozoal risk (Appendix 3 in the DWSNZ).

Sanitary surveys of the catchment, abstraction point, treatment plant, and distribution system should be undertaken by the water supply authority as part of any programme of risk management. They should be conducted with sufficient frequency to be useful in interpreting trends or sudden or significant changes in water quality as revealed by routine monitoring.

The surveys identify potential risks, whilst monitoring can record process performance and water quality trends, whether contamination is occurring, and the extent and the intensity of that contamination.

The USEPA defines a sanitary survey (*Title 40 CFR 141.2)* as an onsite review of the water source, facilities, equipment, operation, and maintenance of a public water system for the purpose of evaluating its ability to produce and distribute safe drinking-water. The sanitary survey should be conducted by qualified persons and identify contamination or deficiencies and inadequacies in the catchment, treatment plant or distribution system, which could result in failure to control contamination should it occur. The USEPA (1999) prepared a sanitary survey guidance manual, which contains a lot of valuable information.

A sanitary survey is indispensable for the proper interpretation of analytical results. No microbiological or chemical survey, however carefully it is made, is a substitute for a thorough knowledge of the conditions at the source and points of abstraction, the treatment process and the distribution system. Sample results represent single points in time; the sanitary survey provides information to determine whether the analytical results are likely to be typical. Contamination may be random and intermittent, and if so, it is rarely revealed by occasional sampling. However, a sanitary survey may identify a potential source of contamination that may then be investigated by targeted monitoring.

A catchment assessment should review such items as land use, whether road or rail systems pass through the catchment, disposal of human and animal wastes, storage and use of chemical contaminants such as pesticides, the presence of existing sanitary landfills and old dumps, release of nutrients, erosion status, levels and disease carrier status of animals (feral, agricultural, and domestic), protection of intake structures from human and animal access, sealing of well casings, protection of wells from flooding, and human access restrictions and security. These factors should be assessed in relation to climatic and hydrological conditions.

The frequency with which catchment sanitary surveys should be performed will be a function of factors such as access control, existing risks, size of population served, accessibility of catchment and seasonal conditions, so cannot be rigidly specified. As a general rule, a thorough survey should be performed every five years, with several less detailed inspections occurring within that period, or when any change in land use or water quality is suspected.

2.2.7 Staff and contractors

The successful management of water supply systems depends on having staff and contractors that have the necessary knowledge and ability to manage and operate the system, identify potential risks and propose improvements.

The procedure for developing a programme to ensure that all staff have the necessary skills and training will typically involve:

1. preparing job descriptions: each employee should have a detailed job description that sets out their duties, key result areas and performance criteria
2. training needs analysis: meetings are normally held with individual staff members to identify gaps between the duties that the staff are required to undertake and their skill level. Training needs are identified and prioritised
3. training programme development: from the training needs analysis the most suitable type of training is determined. Training needs may be a mix of:
   - on-job training
   - off-site training
   - informal meetings and conferences
   - encouragement to belong to professional and technical organisations
   - internal advocacy of the knowledge industry through actions such as internal distribution of technical journals, encouragement to attend local interest meeting
   - recognition of current competencies
4. development and budgeting for a training programme for water staff
5. auditing of the training programme – to assess whether the programme has been initiated and prove that the required levels of competency have been achieved.

The MoH has prepared a PHRMP Guide on Staff Training, Ref G1.

It is recommended that water suppliers undertake a similar process when engaging contractors. This would involve:

1. preparing task descriptions
2. identifying minimum required levels of training and experience
3. detailing required training and experience levels in the contract documents
4. auditing to ensure that the contractor's staff have the required levels of competency.

Water Industry Training has developed a number of national qualifications in partnership with the water industry. The qualifications have been designed to include practical training and assessment at the workplace, complemented with theory-based training through accredited training providers. The qualifications currently available include:

1 *National Certificate in Water Treatment – Site Operator:* includes drinking-water treatment theory, and practical operation of a range of conventional treatment systems. The qualification requires approximately two years of part-time study and on-job learning

2 *National Diploma in Water Treatment – Site Technician:* includes quality assurance, safety, managing and optimising advanced water treatment processes on site. The qualification requires approximately two years of part-time study and on-job learning

3 *National Certificate in Water Reticulation:* includes trenching technology, safety, reticulation systems and disinfection. The qualification requires approximately one year of part-time study and on-job learning

4 *National Diploma in Drinking Water-Assessment:* includes treatment technology, assessing and implementation of WSPs and communications skills. The qualification requires approximately two years of part-time study and on-job learning.

It is also important for water suppliers to have in place a good sanitation and housekeeping programme to ensure that the actions of staff and contractors do not contaminate the water supply. Items typically covered in such a programme would involve:

- all employees and personnel in the plant must wear clean outer clothing
- employees working in the water processing areas must wash and sanitise their hands before returning to the work area and any time when the hands may have become soiled or contaminated
- eating, drinking, smoking, or engaging in any other activity around the water processing areas which may introduce contamination of any kind is prohibited
- an effective hair restraint is required of all employees or personnel in the water processing areas
- no person affected by disease in a communicable form, or while a carrier of such disease, or while affected with boils, sores, or infected wounds, shall work in a water plant in any capacity in which there is any remote possibility of the water supply becoming contaminated by that person, or of a disease being transmitted by such person to other individuals working within the water plant
- only authorised employees and personnel are allowed in the water processing areas
- signs should be posted outlining the above requirements.

2.3 Quality assurance

2.3.1 Key features of quality assurance

The overriding principle of quality assurance is that if the process used to deliver the end product and the factors that impact upon that process are well understood then it is possible to implement measures to control the process so that a product of consistently high quality is achieved.

Whereas risk management focuses more on the actual processes used to deliver the quality end product, quality assurance focuses more on understanding and managing the factors that impact on the processes. In the context of a water supply system, risk management focuses on the processes of collecting, treating and then distributing water and the interrelationships between these processes. But, as well as understanding the risks of the processes, it is equally important to understand other factors that control and support the provision of safe drinking-water – regulatory, organisational structure and processes, human and financial resources.

Examples include:

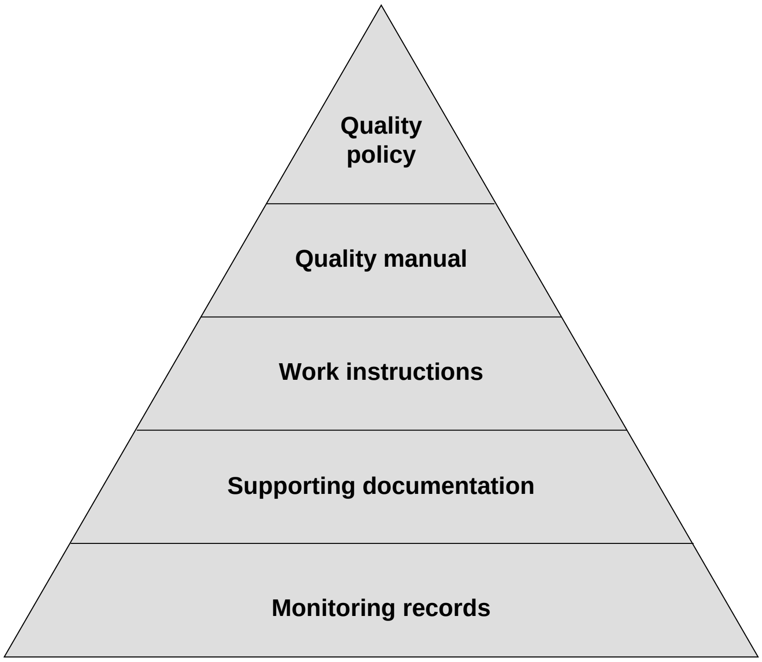
- the Ministry of Health, with their requirements being set out for example in the DWSNZ
- other government agencies, with their requirements being set out in legislation and policies such as Local Government Act and Resource Management Act
- councillors, the community and water users, with their requirements outlined in documents such as by-laws, long term council community plans and supply contracts
- everyone in the organisation is involved and takes responsibility for ensuring that the part of the process for which they are involved is functioning effectively. Responsibility, decision-making and ownership are delegated as far down the chain of command as possible
- there are enough personnel and they have adequate experience and training to undertake their tasks
- there is enough equipment and it is maintained so that it remains accurate and reliable
- standard procedures are in place to provide direction and allocate responsibilities to staff when they are undertaking critical tasks
- monitoring ensures that the systems are working well and provide early warning of possible problems
- surveillance is directed to ensuring that the whole process is right, not merely in checking the quality of the product at the end of the process.

2.3.2 Application to drinking-water supplies

The Public Health Grading of drinking-water sources, treatment plants and distribution systems includes a requirement to have an approved quality management system if the highest grading (A1 for treatment, a1 for the distribution system) is to be achieved, see Chapter 18, section 18.4 for a discussion on aesthetic guidelines methodology. The scope of such a management system would cover all aspects, from source to consumer.

The basic structure of a quality management system that is appropriate for a community drinking-water supply is shown in Figure 2.7.

Figure 2.7: Basic structure for a quality management system



ISO 9001 2000 requires organisations to document the following:

- Quality policy that outlines the organisation's commitment to meet customer, legal and regulatory requirements. The quality policy is supported by the quality objectives the organisation strives to achieve. Quality objectives must be measurable and communicated throughout the organisation. Quality objectives are often developed as part of the preparation of long-term council community plans.
- Quality manual that includes documented procedures for managing the quality system. It is mandatory that the quality manual include documented procedures for:
  - control of documents: they must be legible, identified, reviewed, authorised, distributed and periodically updated
  - control of records: they must be legible and easy to identify and retrieve
  - planning and conducting internal audits: these must be undertaken regularly for each area covered by the quality system. Audit results must be reported, recorded and follow up actions verified

  - non-conforming product (ie, product that does not meet the quality objectives): when non-conformances occur they must be investigated and actions implemented to prevent recurrences
  - preventive actions: the same systems that must be in place for dealing with non-conforming products are required to be in place for dealing with potential problems that have not yet resulted in defective products.

The quality manual is also required to include a description of the interaction of the processes that make up the quality system. This normally takes the form of flowcharts that may for example show the various stages of the collection process and the measures taken to control it and how it interacts with the treatment process. The Ministry of Health's guide *How to Prepare and Develop PHRMPs for Drinking-water Supplies* contains several examples of flowcharts that can be used to describe the water supply process.

- Work instructions: these cover procedures for undertaking specific tasks for which the organisation considers it is necessary to have a documented procedure in place to control the process. Work instructions normally cover:
  - the scope of the procedure, ie, what activities are covered/not covered
  - who is authorised to undertake the task, eg, their required qualifications or experience
  - the procedures that must be followed
  - processes for checking that the work has been completed correctly
  - processes for reviewing, authorising, distributing and updating the work instructions.
- Supporting documentation that includes externally sourced documentation such as manufacturers' manuals, reference standards and operating manuals.
- Records that are kept to demonstrate that the quality system is working correctly. Examples of records normally kept include:
  - training records
  - machinery calibration and maintenance records
  - records from suppliers of materials
  - results of tests and measurements undertaken
  - details of internal audits and follow up actions
  - meeting minutes
  - correspondence.

Documentation can either be paper-based or electronic. Increasingly, organisations are using databases or websites to publish and store documents, as they are easier to update and provide staff with better access than paper-based systems.

The quality assurance system should be seen as a living entity. To stay effective the system needs to be adapted to accommodate items such as changing circumstances, changing requirements, the identification of new hazards, or identification of improved ways of doing things.

Organisations are also tending to produce integrated management systems that cover risk management, asset management, health and safety, environmental and financial matters, as well as quality, all under the same system. In doing so they are recognising that when tasks are being undertaken, employees do not consider, for example, health and safety in isolation, and then quality, but they need to consider all of these aspects at the same time. By developing an integrated management system organisations can simplify the amount of documentation required and develop documentation that reflects the way that work is actually carried out.

2.4 Quality control

Quality control provides the checks to demonstrate that risk management and quality assurance has produced a product that complies with standards, and feedback to the adequacy of risk management. In many situations the DWSNZ have set transgression levels. A transgression may not result in a non-compliance. Using quality control principles, a water supplier will establish control limits, with the aim of triggering some action to prevent the value reaching a transgression level or operational requirement. Control limits, and the actions to be followed when reached, should be covered in WSPs. The Ministry of Health evaluates the compliance of a drinking-water supply with the DWSNZ on a regular basis and uses this in determining the Public Health Grading of community drinking-water supplies and in preparing its annual report on drinking-water quality in New Zealand.

This section discusses compliance in general terms. Chapters 6–11 discuss the DWSNZ compliance criteria and requirements in more detail. Demonstrating compliance with the DWSNZ requires more than demonstrating that the water quality is satisfactory. Other requirements, which are described in more detail in section 3.1.1 of the DWSNZ, include demonstrating:

a) the prescribed number of samples have been taken from the correct places at the prescribed frequencies
b) the samples have been analysed according to approved methods and by a Ministry of Health recognised laboratory
c) compliance requirements have been met for the previous 12-month period
d) the necessary actions have been taken in response to results
e) up-to-date records are kept.

In addition to keeping good records, good quality control practice includes:

a) reviewing results on a regular basis for trends or changes
b) reporting the results to those who need to know – water supply staff, management, health officials, community
c) reviewing and updating WSPs and associated documentation such as procedures.

A national database system for drinking-water, Water Information New Zealand (WINZ), serves a multitude of roles in ensuring water supplies are identified, their water quality assessed and their risks managed. WINZ is the primary database for managing compliance with DWSNZ and public health grading, and records supply-specific characteristics, monitoring results, and responses to transgressions.

2.5 Quantitative microbial risk assessment (QMRA)

WHO (2016) discusses the use of QMRA as a tool in water safety management. The following has been copied:

> QMRA offers a systematic way to use scientific information to help support water safety management decisions on a utility or regulatory level and prioritise remedial actions or research efforts. The numerical output of QMRA addresses the risk management questions in finer detail and allows for more precise comparison between risk management options compared with the qualitative or semi-quantitative approaches. QMRA is a framework or mechanism that allows for quantitative scientific data to be interpreted in the context of estimated health outcomes in order to support water safety management.

For water safety management, the use of QMRA was first proposed in the early 1990s. Since then, QMRA has been used in different levels of detail for drinking-water, recreational water (outdoor and in pools), reuse of domestic wastewater or excreta in agriculture and many other forms of human water use. More detail will come with the expense of more time, more data and expertise; however, the outcome will result in more detailed understanding of the risks and control measures.

QMRA is a formal four-step risk assessment process as shown in the table, where each component of the assessment is explicitly quantified.

Summary of the four-step framework for water-related QMRA:

Step	Description
Problem formulation	The overall context (reference pathogens, exposure pathways, hazardous events and health outcomes of interest) of the risk assessment is defined and constrained in order to successfully target the specific risk management question that must be addressed.
Exposure assessment	The magnitude and frequency of exposure to each reference pathogen via the identified exposure pathway(s) and hazardous events are quantified.
Health effects assessment	Dose–response relationships (linking exposure dose to probability of infection or illness) and probability of morbidity and mortality (depending on the health end-point of the assessment) are identified for each reference pathogen.
Risk characterisation	The information on exposure and the health effects assessment are combined to generate a quantitative measure of risk.

An example of a (deterministic) QMRA to determine the safety of a surface water supply follows.

QMRA to determine treatment performance targets following the WHO GDWQ *Problem formulation*

A drinking-water supply is producing drinking-water from a river, using conventional treatment (coagulation/filtration) and ultraviolet disinfection. This river flows through a number of large urban centres and agricultural lands. Looking at the WHO GDWQ, the utility would like to demonstrate that the drinking-water meets the health outcome target of 10^{-6} DALY per person per year (pppy). Given the human and animal faecal sources in the catchment, the utility wants to include enteric bacteria, viruses and protozoa in the QMRA. It was decided to focus on *Campylobacter,* rotavirus and *Cryptosporidium* as reference pathogens for demonstrating the target is being met. It was also decided to translate the 10^{-6} DALY into treatment performance targets, following the approach in the WHO GDWQ (Table 7.4 in the WHO GDWQ).

Exposure assessment

The utility has no data on the selected reference pathogens *Campylobacter,* rotavirus or *Cryptosporidium* in source water or on pathogen removal by the water treatment processes. Therefore, the utility made an effort to collate data on the occurrence of these reference pathogens in water systems with similar source water (sewage-impacted rivers with limited catchment protection) from the scientific literature. As there was uncertainty about how to translate these literature data to the specific site, the 95th percentile of the literature data from these source waters was selected as input for the QMRA. Limited data on rotavirus were found, so the utility used culturable enterovirus data instead. Similarly, data on the removal of the reference pathogens by coagulation/filtration processes and by UV were taken from scientific literature (review by Hijnen and Medema 2010). For coagulation/filtration, the mean removal deduced from all literature data was used; for the UV disinfection, the local UV fluence setpoint (400 J/m^2) was used to translate the literature data to the local system. For the consumption of (cold) tap water, no local data were available, so 1 L per person per day was used (as assumed in Table 7.4 of the WHO GDWQ).

	Data source	***Campylobacter***	**Rotavirus**[a]	***Cryptosporidium***
Source water (number/L)	95% of data from literature on sewage-impacted rivers	240	0.5	11
Coagulation/filtration (log removal)	Hijnen and Medema (2010)	2.1	3.0	3.2
UV (log removal)	Hijnen and Medema (2010)	>5	4.0	>3

[a] Virus concentration in source water is based on literature data on culturable enterovirus.

Health effects assessment

The dose–response relationships for *Campylobacter,* rotavirus and *Cryptosporidium* that are presented in the WHO GDWQ were used in this QMRA. In the absence of local data on disease burden (DALYs per case) and susceptible fraction of the population for these pathogens, these values were also taken from the WHO GDWQ.

	Data source	*Campylobacter*	Rotavirus[a]	*Cryptosporidium*
Dose–response (probability of infection per organism)	GDWQ Table 7.4	0.019	0.59	0.2
Risk of illness given infection	GDWQ Table 7.4	0.3	0.5	0.7
Disease burden (DALY/case)	GDWQ Table 7.4	4.6×10^{-3}	1.4×10^{-2}	1.5×10^{-3}
Susceptible population (%)	GDWQ Table 7.4	100	6	100

Risk characterisation

The risk management question was to evaluate whether the water supply system was capable of meeting the health outcome target of 10^{-6} DALY pppy. A deterministic QMRA was conducted, based on the data collected from the literature. The main uncertainty is the validity of the use of the literature data for this specific water system. This led to the selection of the 95th percentiles of the concentrations of the reference pathogens as input values for the risk characterisation. The treatment performance target was computed from the difference between the pathogen concentration in source water and the water quality corresponding to the health outcome target of 10^{-6} DALY pppy (see also above). This was compared with the estimated treatment performance (extracted from literature data; Hijnen and Medema 2010), showing that multiple barriers in the treatment were needed and together were capable of producing water that meets the 10^{-6} DALY pppy target.

	Data source	*Campylobacter*	Rotavirus[a]	*Cryptosporidium*
Source water (number/L)	95% of data from literature	240	0.5	11
Pathogen concentration (number/L) in drinking-water corresponding to 10^{-6} DALY pppy[b]	–	1.1×10^{-4}	1.1×10^{-5}	1.3×10^{-5}
Required log removal to meet health-based target (performance target)	–	6.3	4.7	5.9
Calculated log removal	–	>7.1	7.0	>6.2
Coagulation/filtration	Hijnen and Medema (2010)	2.1	3.0	3.2
UV	Hijnen and Medema (2010)	>5	4.0	>3

a Virus concentration in source water is based on literature data on culturable enterovirus.

b From Table 7.4 of the WHO GDWQ.

QMRA requires more technical knowledge and resources compared with the risk assessment approaches presented previously. The level of quantification, mathematical sophistication, time, expertise and data required depend on the level of sophistication of the QMRA. Conducting a comprehensive probabilistic QMRA requires the most resources in terms of data and specialised personnel. In practice, such comprehensive QMRAs are conducted mainly in larger utilities in high-income countries where the public health agencies have promoted the use of QMRA by providing guidance or even direct support.

Application

QMRA calculations have historically been in the hands of specialists and researchers. The apparent complexity of the calculations has created a barrier for more widespread accessibility to the water industry. Various tools have been developed to increase accessibility of the QMRA approach to non-specialists. A range of different software platforms have been used to undertake QMRA calculations. Petterson and Ashbolt (2016) note that:

- there is currently no single QMRA tool that can meet all of the needs of the water industry
- basic training in QMRA and understanding the underlying model assumptions is necessary to support tool implementation
- there is limited value associated with a 'black box' QMRA tool, as the greatest value is not in the result alone, but in understanding the interactions between the model parameters and relative risk estimates – so you get to know your system
- more complex studies are not necessarily better, in fact, a QMRA should be as simple as possible in order to achieve the required outcomes of the analysis
- in practice, whilst the QMRA methodology is fundamentally robust, its reliability is limited by the quality of supporting data and evidence.

References

ANSI/AWWA G100-11. 2011. *Water Treatment Plant Operation and Management* (1st edition). Denver CO: AWWA Standard, American Water Works Association.

ANSI/AWWA G410-09. 2009. *Standard for Business Practices for Operation and Managemen*t. Denver CO: AWWA Standard. American Water Works Association.

AS/NZS ISO 9001. 2000. *Quality Management Systems – Requirements*. Standards Australia/Standards New Zealand.

AS/NZS. 2004. AS/NZS 4360:2004. *Risk Management*. Standards New Zealand.

AWWA. 1994. Overcoming natural disasters. Articles by Reid, McMullen, Murphy and Shimoda in *Journal American Water Works Association* 86(1).

AWWA. *Manual M5: Water Utility Management*. Denver CO: American Water Works Association. **www.awwa.org**

CDC. 2010. *When Every Drop Counts: Protecting public health during drought conditions – a guide for public health professionals*. Centers for Disease Control and Prevention, US Environmental Protection Agency, National Oceanic and Atmospheric Agency, and American Water Works Association. Atlanta: US Department of Health and Human Services, 56 pp. See **http://www.cdc.gov/nceh/ehs/Publications/Drought.htm**

Codex Alimentarius. 1993. *Guidelines for the Application of the Hazard Analysis Critical Control Point (HACCP) System*. CAC/GL 18-1993.

DWI. 2012. *Health Impacts from Extreme Events Water Shortages*. 92 pp. **http://dwi.defra.gov.uk/research/completed-research/reports/DWI70-2-263.pdf**

EnHealth. 2012. *Risky Business – A resource to help local governments manage environmental health risks*. Commonwealth of Australia, Environmental Health Standing Committee and the Australian Government Department of Health and Ageing, Canberra. 74 pp.
http://www.health.gov.au/internet/main/publishing.nsf/Content/health-pubhlth-publicat-environ.htm

Geldreich EE. 1996. *Microbial Quality of Water Supply in Distribution Systems*. Boca Raton: CRC Lewis Publishers.

ISO. 2009. AS/NZS ISO 31000:2009 – Risk management – Principles and guidelines.

MoH. *Public Health Risk Management Plan Guides*. The New Zealand Ministry of Health's Guides for drinking-water supplies can be accessed as Word documents on the Ministry of Health website: **http://www.health.govt.nz/water** then select publications and Water Safety Plans. First, read: How to prepare and develop PHRMPs.

MoH has prepared a PHRMP Guide on Staff Training, Ref. G1.

MoH. 2005. *Drinking-water Standards for New Zealand*. Wellington: Ministry of Health. This version was revised 2008.

MoH. 2008. *Guidelines for the Safe Carriage and Delivery of Drinking-water.* Wellington: Ministry of Health. Available online at **http://www.health.govt.nz/water**.

MoH. 2008. *Small Drinking-water Supplies: Public health risk management kit.* Available online at **http://www.health.govt.nz/water**.

MoH. *Register of Community Drinking-water Supplies and Suppliers in New Zealand.* Wellington: Ministry of Health.

NHMRC. 2012. *Australian Drinking Water Guidelines, Community Water Planner – A tool for small communities to develop drinking water management plans, Community Water Planner, User Manual*. **www.nhmrc.gov.au/guidelines/publications/eh52web** or **http://www.nhmrc.gov.au/publications/synopses/eh39.htm** or **http://www.communitywaterplanner.gov.au/resourceportal/35**.

NHMRC. 2016. *Australian Drinking Water Guidelines*. National Health and Medical Research Council. **https://www.nhmrc.gov.au/guidelines-publications/eh52**.

NZS. 2000. SNZ HB 4360:2000. *Risk Management for Local Government*. Standards New Zealand.

Petterson SR, Ashbolt NJ. 2016. QMRA and water safety management: review of application in drinking water systems. *J Water Health* 14(4): 571–89. **https://doi.org/10.2166/wh.2016.262**.

USEPA. 1999. *Guidance Manual for Conducting Sanitary Surveys of Public Water Systems; Surface Water and Ground Water Under the Direct Influence (GWUDI)*. EPA, United States Office of Water. EPA 815-R-99-016. Environmental Protection Agency. April. See **http://www.epa.gov/safewater/mdbp/pdf/sansurv/sansurv.pdf**.

USEPA. 2004. *Response Protocol Toolbox: Planning for and responding to drinking water contamination threats and incidents*. Module 5: Public Health Response Guide. Interim Final – April 2004. 83 pp. **http://water.epa.gov/infrastructure/watersecurity/upload/guide_response_module5.doc**.

Water UK. 2010. *Medical Surveillance of Personnel*. Technical Guidance Note No.1. 2 pp. **http://www.water.org.uk/home/policy/publications/archive/drinking-water/principles-of-water-supply-hygiene**.

Water UK. 2010a. *Event and Incident Management*. Technical Guidance Note No.10. 5 pp. **http://www.water.org.uk/home/policy/publications/archive/drinking-water/principles-of-water-supply-hygiene**.

WHO. 2001. *Water Quality – Guidelines, Standards and Health: Assessment of risk and risk management for water-related infectious disease*. Published on behalf of the World Health Organization by IWA Publishing. This book is available on the internet at: **http://www.who.int/water_sanitation_health/dwq/whoiwa/en/index.html**.

WHO. 2003. *Environmental Health in Emergencies and Disasters: A practical guide*. ISBN 92 4 154541 0. Chapter 7 discusses water supply. Available on the internet at: **http://www.who.int/water_sanitation_health/hygiene/emergencies/emergencies2002/en/**.

WHO. 2004. *Guidelines for Drinking-water Quality 2004* (3rd edition.). Geneva: World Health Organization. **http://www.who.int/water_sanitation_health/dwq/guidelines/en/index.html** and see also the addenda (2006).

WHO. 2005. *Water Safety Plans: Managing drinking-water quality from catchment to consumer*. WHO/SDE/WSH/05.06. 244 pp. **http://www.who.int/water_sanitation_health/dwq/wsp170805.pdf**.

WHO. 2007. *Chemical Safety of Drinking-water: Assessing priorities for risk management*. Thompson T, et al. 160 pp. Geneva: World Health Organization. See: **http://www.who.int/water_sanitation_health/dwq/dwchem_safety/en/**.

WHO. 2009. *Water Safety Plan Manual (WSP Manual): Step-by-step risk management for drinking-water suppliers*. How to develop and implement a Water Safety Plan – A step-by-step approach using 11 learning modules. 108 pp. **http://www.who.int/water_sanitation_health/publications/en/index.html**.

WHO. 2011. *Water Safety Plan Manual Quality Assurance Tool* – User Manual. 28 pp. **http://www.who.int/water_sanitation_health/publications/en/index.html**.

WHO. 2011a. *WHO Technical Notes on Drinking-water, Sanitation and Hygiene in emergencies*. **http://www.who.int/water_sanitation_health/dwq/publications/en/index.html**.

WHO. 2011b. *Guidelines for Drinking-water Quality 2011* (4th edition). Geneva: World Health Organization. Available at: **http://www.who.int/water_sanitation_health/publications/2011/dwq_guidelines/en/index.html**.

WHO. 2012. *Water Safety Planning for Small Community Water Supplies Step-by-Step Risk Management Guidance for Drinking-water Supplies in Small Communities*. 66 pp. **http://www.who.int/water_sanitation_health/publications/2012/water_supplies/en/index.html**.

WHO. 2013. *Health and Environment: Communicating the risks*. WHO Regional Office for Europe, Copenhagen. 68 pp. ISBN 978 92 890 00512. **http://www.euro.who.int/__data/assets/pdf_file/0011/233759/e96930.pdf**.

WHO. 2014. *Water Safety Plan: A field guide to improving drinking-water safety in small communities*. WHO Regional Office for Europe. 100 pp. **http://www.euro.who.int/en/health-topics/environment-and-health/water-and-sanitation/publications/2014/water-safety-plan-a-field-guide-to-improving-drinking-water-safety-insmall-communities**.

WHO. 2015. *A Practical Guide to Auditing Water Safety Plans*. 88 pp. Geneva: World Health Organization. Available at: **http://www.who.int/water_sanitation_health/dwq/audit-for-wsp.pdf**.

WHO. 2016. *Quantitative Microbial Risk Assessment: Application for water safety management*. World Health Organization. Geneva. 208 pp. **http://www.who.int/water_sanitation_health/dwq/** or **http://apps.who.int/iris/bitstream/10665/246195/1/9789241565370-eng.pdf?ua=1**.

WHO. 2016a. *Protecting Surface Water for Health: Identifying, assessing and managing drinking-water quality risks in surface water catchments*. 196 pp. **http://www.who.int/water_sanitation_health/publications/pswh/en**.

WHO. 2017. *Guidelines for Drinking-water Quality: Fourth edition incorporating the first Addendum*. Geneva: World Health Organization. 631 pp. **http://www.who.int/water_sanitation_health/publications/drinking-water-quality-guidelines-4-including-1st-addendum/en/**.

WHO. 2018. *Strengthening Operations and Maintenance through Water Safety Planning*. A collection of case studies. 20 pp. WHO/CED/PHE/WSH/18.69. WHO/IWA. **http://www.who.int/water_sanitation_health/publications/strenghtening-om-thru-water-safety-planning/en/**.

WQRA. 2009. *Risk Assessment for Drinking Water Sources*. Research Report No 78. 65 pp. **http://www.wqra.com.au/project-details/2**.

WRA. 2015. *Good Practice Guide to the Operation of Drinking Water Supply Systems for the Management of Microbial Risk*. Final Report – WaterRA Project 1074. Water Research Australia Limited. 52 pp. ISBN 978-1-921732-27-0. **http://www.waterra.com.au/publications/document-search/?download=1173**.

WRF. 2016. *A Methodology for Locating and Managing Dynamic Potential Source Water Contaminant Data*. Project #4581. Denver, Colo.: Water Research Foundation. Author: Rosen et al. 175 pp. **http://www.waterrf.org/PublicReportLibrary/4581.pdf.**