5

Understanding the hazards and threats

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

5.1 HAZARD IDENTIFICATION

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

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

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

identify what could happen to lead to contamination; and

the associated control measures for

each hazard.

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

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

5.1.1 Biological hazards

These hazards include frank and opportunistic pathogens such as:

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

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

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

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

5.1.2 Chemical hazards

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

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

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

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

5.1.3 Physical hazards

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

5.1.4 Radiological hazards

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

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

5.2 HAZARDOUS EVENTS

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

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

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

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

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

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

5.3 PRIORITISING HAZARDS

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

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

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

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

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

5.3.1 Prioritisation matrix

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

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

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

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

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

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

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

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

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

5.4 MELBOURNE WATER CASE STUDY – HAZARD ANALYSIS

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

Table 5.3: Melbourne Water consequence/probability matrix

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

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

Table 5.4: Melbourne Water significance scale

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

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

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

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

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

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

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

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

5.5 KAMPALA CASE STUDY – HAZARD ANALYSIS

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

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

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

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

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

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

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

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

Cat - Catastrophic

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

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

Cat – Catastrophic; Med - Medium