

Application of a risk management system to improve drinking water safety

Asoka Jayaratne

ABSTRACT

The use of a comprehensive risk management framework is considered a very effective means of managing water quality risks. There are many risk-based systems available to water utilities such as ISO 9001 and Hazard Analysis and Critical Control Point (HACCP). In 2004, the World Health Organization's (WHO) Guidelines for Drinking Water Quality recommended the use of preventive risk management approaches to manage water quality risks. This paper describes the framework adopted by Yarra Valley Water for the development of its Drinking Water Quality Risk Management Plan incorporating HACCP and ISO 9001 systems and demonstrates benefits of Water Safety Plans such as HACCP.

Key words | emergency, guidelines, health, risk management, water quality, water supply

Asoka Jayaratne
Senior Planning Engineer,
Yarra Valley Water,
Private Bag 1, Mitcham, VIC3132
Australia
Tel.: 61-3-9872 1398,
Fax: 61-3-9872 1530,
E-mail: asoka.jayaratne@yvw.com.au

ABBREVIATIONS

ADWG	<i>Australian Drinking Water Guidelines</i> (Australian Government 2004)
AEDST	Australian Electronic Decision Support Tool
CCP	Critical Control Point
<i>E.coli</i>	<i>Escherichia coli</i> . A bacterium found in the gut of warm blooded animals that is used as an indicator of faecal contamination.
HACCP	Hazard Analysis and Critical Control Point. An industry recognised preventive risk management system which identifies, evaluates and controls hazards associated with the production of safe food or water
NASA	National Aeronautics and Space Administration
WHO	World Health Organization

INTRODUCTION

Water utilities have the vital responsibility of managing water quality risks to ensure the safety and quality of water supplied to their customers. In Milwaukee, Wisconsin in 1993, *Cryptosporidium* contamination of the public water

doi: 10.2166/wh.2008.061

supply caused more than 100 deaths and an estimated 403,000 illnesses. Contaminated drinking water killed seven people and sickened 2,300 in Walkerton, Canada in 2000 (Anon 2005). These and events in other countries prompted an urgency to implement risk management systems and move away from the reliance of water quality monitoring results to ensure the safety of drinking water.

In 1998, Yarra Valley Water realised that its existing water quality management system had potential for improvement as it focused on end product testing at the property supply point to customers. Relying on end product testing has serious shortcomings in minimizing the impact on customers, if a water quality event occurs. For example in the case of pathogens such as *Giardia* or *Cryptosporidium* it could be in excess of three days before detection would be reported from the testing laboratory.

Yarra Valley Water chose to use the Hazard Analysis and Critical Control Point (HACCP) system, which had been widely established in the food industry in Australia since the 1980s, and is a proven proactive risk management system for ensuring product safety.

This paper describes the key components of the Company's HACCP system and demonstrates benefits of

the implementation of Water Safety Plans such as HACCP to manage water quality risks. The paper also demonstrates that in most cases Water Safety Plans can be developed quite easily, irrespective of the size of the water supply, focusing on management of key hazards. A clear commitment to the development and application of preventive risk management to support the delivery of safe drinking water combined with supporting programs including basic elements of good management practices and continuous evaluation and audit processes are essential elements of Water Safety Plans.

Yarra Valley Water is the largest Victorian State Government owned retail Water Company in Melbourne, Australia. It provides water and sewerage services to 1.6 million people in the northern and eastern suburbs of Melbourne.

Yarra Valley Water was one of the first water utilities in the world to apply HACCP to its water supply in 1999 and achieve accreditation to the international standard of HACCP 9000. Whilst HACCP systems have been implemented in the Australian water sector over the past seven years, the concept of Water Safety Plans is new to the developing countries. Bangladesh, Ghana and Uganda have active programs to implement the WHO [Guidelines for Drinking Water Quality \(2004\)](#) through the use of risk assessment and implementation of Water Safety Plans ([Deere 2005](#)). These plans are still at their early stages and will be the initial step towards implementing complete HACCP systems over time. The key challenges in implementing HACCP systems especially in low income environments are also discussed in the paper.

RISK MANAGEMENT SYSTEMS

Risk-based systems available to water utilities include ISO 9001, ISO 14001, HACCP and the local standards such as the Australia New Zealand Risk Management Standard AS/NZS 4360. The advantage of ISO and HACCP systems is that certification can be achieved showing that peer review has been undertaken to reach the appropriate standard ([Davison & Deere 2005](#)).

What is HACCP?

HACCP is an internationally recognized process control system which involves identifying and prioritizing hazards and risks to product quality and controlling processes to reliably maintain the desired level of product quality. The application of HACCP principles in a systematic manner ensures that water quality risks are controlled as close to their sources as possible.

The HACCP concept was developed in the US in 1959 by the Pillsbury Company to improve food safety for manned space missions by the National Aeronautics and Space Administration (NASA). Since the 1980s the HACCP system has been widely adopted by food and beverage industries world wide.

There are 12 steps of HACCP as defined by the [Codex Alimentarius Commission \(1993\)](#), an intergovernmental body established to implement the Joint Food and Agricultural Organization (FAO)/ WHO Food Standards Program. The information prepared in completing these 12 steps constitutes HACCP Plan. These steps are:

- | | |
|---------|--|
| Step 1 | Assemble HACCP team |
| Step 2 | Describe product |
| Step 3 | Identify intended use |
| Step 4 | Construct flow diagram |
| Step 5 | Confirm flow diagram |
| Step 6 | Conduct a hazard analysis |
| Step 7 | Determine the critical control points |
| Step 8 | Establish critical limits |
| Step 9 | Establish a system to monitor control of the critical control points |
| Step 10 | Establish corrective actions |
| Step 11 | Validation and verification of HACCP plan |
| Step 12 | Establish documentation and record keeping. |

The application of the 12 HACCP steps requires their implementation with a broader HACCP System that includes Supporting Programs. Supporting Programs also known as Good Management Practices should be in place prior to embarking on the 12 HACCP steps. Yarra Valley Water's Supporting Programs include:

- Distribution system maintenance programs such as cleaning and inspection of storages, cleaning of water

mains, corrosion prevention program, water mains renewal and replacement program, backflow prevention program

- Standard operating procedures including asset operation protocols, water quality monitoring and exceedence management, customer complaints management, water main repair practices, disinfection failure response procedures
- Emergency and incident response plans
- Quality assurance programs
- Data management systems
- Customer communication and consultation
- Annual staff training
- Annual reviews and third party audits

YARRA VALLEY WATER'S HACCP SYSTEM

Yarra Valley Water chose a two step process to develop its HACCP system. In the first step, the business used an engineering consultant to identify all potential risks to the water supply system. Secondly, a consultant with HACCP experience from the food industry was used to facilitate the HACCP plan development.

Yarra Valley Water receives treated (only 15% fully filtered) water from its wholesaler Melbourne Water. Therefore, Yarra Valley Water's HACCP Plan does not include water quality risks in the catchments and treatment plants. These risks have been addressed in a separate HACCP Plan prepared by the wholesaler. The HACCP system received accreditation to the international HACCP 9000 standard in December 1999.

Assemble HACCP team (step 1)

The HACCP team is responsible for the planning, development, verification and implementation of the HACCP system. Yarra Valley Water's HACCP team consists of ten members with a broad range of skills across the Company representing planning, design, construction, operation and maintenance functions. There are four working groups each comprising up to five members:

- Treatment and storages team
- New assets team

- Backflow prevention team
- Mains alteration team

These teams are responsible for the risk assessment in each of their respective sub areas. Teams undertake review of the HACCP system as necessary and at a minimum frequency of 12 months.

Describe product (step 2)

The product for water utilities can be described as potable water. A detailed description of the product is provided as a list of key water quality standards/targets that need to be achieved at the customer's property. These targets are based on the regulatory requirements, business key performance indicators and Australian Drinking Water Guideline limits. Two typical water quality compliance targets from Yarra Valley Water's product description list are shown in Box 1. Product description includes compliance targets for total coliforms, disinfection-by-products, turbidity, aluminum, copper, fluoride, manganese, pH, colour and hardness.

Identify intended use (step 3)

A clear statement of the intended use of the product (potable water) was prepared as shown in Box 2.

Construct flow diagram (step 4 & step 5)

The HACCP team developed a process flow chart for the distribution system using the standard symbols (Figure 1).

A simple flow diagram (Figure 2) was constructed to describe the key steps in the water supply process. The level

Box 1. Product specification

E.coli – 98% of the samples taken in each water quality zone in a rolling 12 month period must not contain *E.coli* bacteria.

Iron - 95% upper confidence limit of the mean for samples over a 12 month period must be less than 0.3 mg/L.

Box 2. Intended use

Potable water intended for general human consumption.

Symbol	Description
○	Operation
⇨	Transport
▽	Storage
□	Inspection

Figure 1 | Standard HACCP symbols. Source: Yarra Valley Water HACCP Plan.

of details in the flow diagram can vary as decided by the HACCP team. The flow diagram is then confirmed to ensure that all process steps have been included. Once the Critical Control Points are determined (step 7), they are also shown in the flow diagram.

Yarra Valley Water’s wholesaler Melbourne Water controls the catchment and treatment steps in the process and hence the flow diagram commences from the water receipt step.

Conduct a hazard analysis (step 6)

The HACCP team used technical expertise in system operation of its members and historical data to prepare a list of microbiological, physical and chemical hazards at each process step from the water receipt through to customer interface. Current control measures were

identified to ensure that each hazard can be managed at acceptable levels. Some examples of identified hazards are:

- Contamination due to receipt of untreated water due to upstream treatment failures
- Biological contamination due to algae
- Microbiological contamination due to main bursts
- Chemical contamination due to corrosion of water mains and steel storage tanks
- Contamination due to sloughing of biofilms from pipes due to high flows
- Physical contamination due to resuspension of natural sediments in reticulation due to high flows
- Chemical contamination due to backflow from industrial commercial customers

There are a number of alternative approaches to undertake hazard analysis. Yarra Valley Water adopted a simple semi quantitative risk matrix (Table 1) to assess risks. The risk assessment can take up to several days depending on the complexity of the system. Two one day workshops were adequate to assess Yarra Valley Water’s system.

The HACCP team decided that a risk ranking score greater than 5 was “significant”. Once hazards were identified and ranked according to their likelihood of occurrence and severity of consequences, the HACCP team focused on elimination or reduction of the highest ranked hazards to acceptable levels. This was accomplished in HACCP step 6 through to step 10. The HACCP team then identified existing control measures and any additional control or preventive measures that systems may require for future operations.

Table 1 | Risk matrix

Likelihood	Severity
1 = Once every five years or less	1 = No impact or not detectable
2 = Once per year	2 = Impact on potential customer complaints
3 = Once per month	3 = Impact on customer contract compliance
4 = Once per week	4 = Impact on licence compliance
5 = Once per day or more	5 = Impact on public health

Total assessed risk (risk ranking score) = Likelihood × Severity. Source: Yarra Valley water HACCP plan.

	Description	Symbol	Details
CCP	Treated water receipt from wholesaler	○	Includes (0.1%) customers supplied from assets not controlled by Yarra Valley Water
	Transfer	⇨	> 750 mm diameter
CCP	Storage	▽	Closed storage
	Distribution	⇨	300 mm to 750 mm diameter
CCP	Reticulation	⇨	< 300 mm
	Customer interface	⇨	

Figure 2 | Water supply system flow diagram. Source: Yarra Valley Water HACCP Plan.

Specific control measures identified include:

- Bulk water supply agreement with the wholesaler to ensure the quality of water received
- Wholesaler's individual chlorinator outage management plans at primary disinfection plants
- Contingency plan for open reservoirs during algal events
- Water mains burst repair procedure
- Water mains renewal program
- Water mains cleaning procedures
- Backflow prevention program
- Annual tank cleaning program
- Surveillance cameras at high risk tank sites
- Spot chlorination procedure for tanks
- Contract specifications and contractor's project management plans for construction of new assets

The three significant risks identified for Yarra Valley water system are shown in Box 3.

Determine the Critical Control Points (step 7)

A Critical Control Point (CCP) is a step in the water supply system where control measures are essential and can be applied to maintain the safety of the drinking water and are distinct from control measures. These critical barriers are shown as CCPs at "Process Steps" on the flow diagram (Figure 2). The three significant hazards (Box 3) are continuously monitored and controlled to ensure they do not pose a significant water quality or safety risk.

Establish critical limits (step 8)

For each CCP identified in the process, measurable parameters and limits for each parameter were established. Current knowledge and expertise including industry standards, as well as historical data, were used as a guide

Box 3. Critical control points

- Receipt of untreated water from the wholesaler due to disinfection plant failures;
- Security breaches at storage reservoirs; and
- Incidents which cause widespread customer complaints due to events such as resuspension of sediments or particles and operational activities

to determine the limit. Critical limits for the CCP of disinfection plant failure are shown in Box 4.

Establish a system to monitor control of the critical control points (step 9)

For each CCP it is vital to establish a monitoring procedure to:

- Ensure the process step is under control and determine when a deviation occurs from the target control limit
- Provide records that can be examined during the verification step
- Track the effectiveness of the operation over time.

Monitoring procedure for the CCP of disinfection plant failure is shown in Box 5.

Yarra Valley Water continuously monitors the critical limits for each CCP. Any violations and subsequent corrective actions are recorded in a database. The historical CCP violations are routinely analysed to identify further system improvements. The benefits of such analysis are explained in the section "Benefits of HACCP" under the sub heading "Disinfection Plant Reliability".

Establish corrective actions (step 10)

For every monitoring procedure, corrective actions need to be developed when target criteria and critical limits have been deviated to ensure that the critical control point is brought under control or that unsafe water has been disposed of in a correct and appropriate manner. All corrective actions undertaken are recorded in the HACCP system to prove that

Box 4. Critical limits for the chlorinator failure CCP

- Receipt of notification of primary chlorinator failure from the wholesaler Melbourne Water.
- Wholesaler's trigger for alarms is set point ± 0.2

Box 5. Monitoring procedure for the chlorinator failure CCP

- Wholesaler's Duty Officer notifies Manager Water Operations by telephoning and confirms by fax.
- After hours notification protocols.
- Wholesaler's alarms and continuous chlorine monitoring

Box 6. Corrective actions for the chlorinator failure CCP

- Isolate interface transferring unchlorinated water and redirect safe supply to customers. Flush unchlorinated water from distribution system. Disinfect tanks.
- For prolonged outages instigate Emergency Response Plan for Water Quality.
- Actions recorded in Yarra Valley Water Incident Management System.
- Incident debriefs to assess corrective action and determine further action.

all reasonable precautions have been taken in accordance with due diligence. Some corrective actions for the CCP of disinfection plant failure are shown in Box 6.

Validate/verify HACCP plan (step 11)

Verification is the process of confirming that the HACCP system has been accurately implemented and is working as designed. In other words, all hazards have been identified and that CCPs, critical limits, monitoring and corrective action procedures are appropriate and effective.

Yarra Valley Water's HACCP system includes a comprehensive verification schedule which describes the verification activity, review frequency, person responsible and how and where relevant records are kept. The validation/verification activities are shown in Box 7.

Internal and third party audits are conducted annually to verify that the HACCP system is functioning as designed. Any improvements recommended during the audits are recorded in the Company's intranet, responsibilities assigned to individual staff, progress monitored and tracked via an automated tracking system to ensure that actions are taken to implement improvement programs.

Box 7. Validation examples

- Water quality monitoring
- Review raw material supplier performance
- Review customer complaints
- Review staff training
- Audit HACCP plan
- Review monitoring and corrective action records
- Review hazards and control measures
- Validate critical limits
- Review of inspection measurements and test equipment

Establish documentation and record keeping (step 12)

"Efficient and accurate record keeping is essential to the application of a HACCP system" (Codex Alimentarius Commission 1993). It provides retrospective proof of compliance to the HACCP plan and enables product traceability and facilitates continuous improvement from trend analysis. Yarra Valley Water maintains hardcopy and electronic record keeping and tracking systems, asset information management databases and a water quality data base in accordance with its ISO accreditation systems. Business wide monthly and annual reporting systems have also been in place.

BENEFITS OF HACCP

Since the implementation of HACCP, Yarra Valley Water has been able to identify and implement a number of improvement programs to prevent or minimise water quality risks (Chapman *et al.* 2003). These improvements have been identified through continuous management of the HACCP processes.

Non reliance on end point testing

The non reliance on end product testing to manage risks is a key benefit. HACCP prevents or minimises the risks in the water supply process by identifying and managing them at the earliest instance. End product testing data is now used to verify that the HACCP process and in turn the water supply system is working as designed.

Disinfection plant reliability

Yarra Valley Water receives its supply from the wholesaler Melbourne Water. The wholesaler is responsible for disinfecting the water supply prior to it entering the retailer's water supply pipe network. The supply of undisinfected water by Yarra Valley Water's wholesaler due to a disinfection plant failure is a Critical Control Point in the HACCP Plan. As a result of continuous monitoring of short term outage or plant failures, Yarra Valley Water have been able to identify trends and initiate plant improvements with the wholesaler. The wholesaler has implemented

improvements including site specific chlorinator outage response plans, plant design modifications, operator training and action levels for interface chlorine residuals where disinfected water passes through wholesaler's storages prior to entering the Yarra Valley Water supply network. These improvements have resulted in a significant reduction in the number of plant down time or failures in the last five years. Yarra Valley Water certification auditors who conduct annual audits commended these improvements. Reductions in CCP violations are shown in Figure 3.

Review of disinfection contact time

HACCP reviews identified some smaller chlorinated systems that did not meet the minimum disinfection contact time requirements for all demand scenarios. The investigations contributed to the wholesaler installing primary Ultra Violet disinfection plants up stream of the chlorinator plants.

Emergency response for chlorinator failure

Yarra Valley Water have developed a user friendly corrective action plan for a number of small systems using hydraulic models to simulate the location of any slugs of undisinfected water during chlorinator failures. Yarra Valley Water operations staff are now able to pin point the location of undisinfected water and promptly undertake flushing activities in the field to maximise the removal of this water from mains and there by minimise the amount of unchlorinated water supplied to customers.

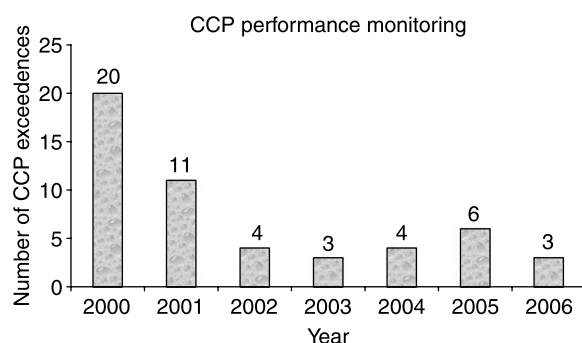


Figure 3 | Reduction in CCP violations.

Backflow management

The review of risk assessment for Backflow assisted Yarra Valley Water to identify gaps in its Backflow Prevention Program. A dedicated Backflow Prevention Officer was appointed to manage about 55,000 industrial and commercial customers. Yarra Valley Water has reviewed the backflow policy to introduce strict compliance requirements for all new connections to the water supply system. Yarra Valley Water is now working to refine the risk ranking of all customers and have allocated resources to achieve 100% compliance for backflow.

Security management

Security breeches at storage tanks is one of the three CCPs. Yarra Valley Water have implemented a number of improvement projects (identified pre 11 September 2001) to prevent or minimise this risk and also corrective actions in the event of any breach of security. These include risk ranking of storages, installation of special locking systems, installation of special protective devices for hatches and hatch alarms and targeted site inspections.

Improved reporting

Yarra Valley Water have developed a fully automated monthly reporting process for water quality performance to ensure the water supplied by the wholesaler meets the specifications that are included in the Bulk Water Supply Agreement. This process has enabled Yarra Valley Water to identify product specification violations and negotiate improvements with the wholesaler.

Integrating with wholesaler's HACCP system

The HACCP plans of Yarra Valley Water and its wholesaler are complementary as they represent risks from catchment to customer property. Yarra Valley Water is regularly meeting with the HACCP system managers of the wholesaler to identify system shortfalls and develop solutions.

RISK MANAGEMENT FRAMEWORK FOR WATER SUPPLY

The *Australian Drinking Water Guidelines* in its 6th revision in 2004 (ADWG) (Australian Government 2004) pioneered the concept of a “Framework for Management of Water Quality” to manage water quality risks. This Framework which encompasses management of all risks from the catchment to customer using the principle of multiple barrier approach was adopted by the World Health Organisation (WHO) in its third edition of the *Drinking Water Guidelines*. Yarra Valley Water’s innovative approach in 1999 to apply HACCP to its water supply (*Drinking Water HACCP Plan 1999*) proved invaluable for the development of its Risk Management Plan in 2005.

State Government of Victoria introduced legislation in 2004 which require all water utilities in the State to develop and implement Risk Management Plans to manage water quality. The Company adopted the ADWG Framework in developing its *Drinking Water Risk Management Plan (2005)*. The plan has been implemented since 1 July 2005. Company’s HACCP, ISO 9001, ISO 14001 systems and other business processes form the basis for meeting the requirements in the ADWG. The Framework for management of water quality addresses four general areas:

1. **Commitment to Drinking Water Quality Management** – this involves developing a commitment to drinking water quality management within the organisation. Adoption of the Framework without effective implementation and continual improvement is not sufficient. Successful implementation requires the active participation of senior executives and a supportive organisational philosophy.
2. **System Analysis and Management** – this area involves understanding the entire water supply system, the hazards and events which can compromise drinking water quality, and the preventive measures and operational control necessary for assuring safe and reliable drinking water.
3. **Supporting Requirements** – this area involves elements needed to ensure the capacity to operate and adapt a system to meet its challenges. This includes the basic elements of good practice such as employee training,

community involvement, research and development, validation of process efficacy, and documentation and reporting systems.

4. **Review** – this area includes regular evaluation of water quality data and audit processes, and their review by senior executives to ensure that the management system is functioning satisfactorily. These components provide a basis for review and continual improvement.

The elements of the Framework and the linkage between the four areas are illustrated in [Figure 4](#).

Preventive risk management systems such as HACCP supported by good management practices are necessary to satisfy the requirements of the Framework. The ADWG provides further guidance on the adequacy of such systems to manage water quality risks.

Yarra Valley Water has assessed its water supply system against requirements of each element and demonstrated its HACCP and ISO systems adequately address the requirements of 23 of the 31 elements of the Framework. Other business processes such as community consultation protocols, incident and emergency management plans, participation in water quality research programs and automated tools for short and long term evaluation of water quality data adequately address the remaining eight elements not addressed by ISO or HACCP systems. The Risk Management Plan details how compliance with criteria for each element is achieved.

CHALLENGES IN APPLYING HACCP IN DEVELOPING COUNTRIES

To obtain HACCP “certification” for water delivered at the point of supply it would be necessary to ensure that water is adequately treated and/or sourced from a safe source and then to maintain a continuously pressurised, closed distribution system if a piped network is used. The common practice of not maintaining pressurised systems is a major obstacle to supplying reliable, safe water and gaining HACCP certification in water supply systems in developing countries. It is well established that some contamination arises during depressurised periods in piped systems. In recent years, many South Asian systems have become adequately treated and/or sourced from good sources and are safe at the point of delivery into the piped distribution

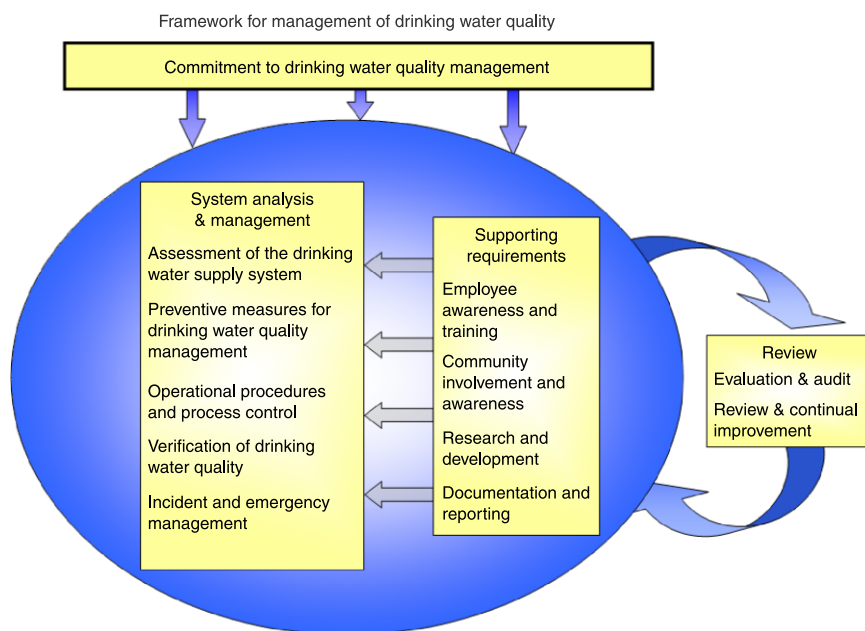


Figure 4 | Risk management framework in the Australian drinking water guidelines (Australian Government 2004). Source: Cooperative research centre for water quality and treatment, Australia.

system. Therefore, it is possible to obtain HACCP certification just for the water leaving the treatment plant.

Another option is to apply the principles of HACCP by developing a Water Safety Plan which aims to maximise water safety within the constraints of the system. For example, it may not be possible to produce water which reliably meets international standards and can be HACCP “certified”, but it may be possible to improve water safety by applying the HACCP principles. A key outcome of such an activity would be an “Improvement Action Plan” which sets out the way in which water safety would gradually be improved over time. This approach has recently been adapted in Bangladesh for a water supply sourced from ground water. Bangladesh has an active program to implement the WHO *Guidelines for Drinking Water Quality* (WHO 2004), through use of risk assessment, implementation of Water Safety Plans, and development of a surveillance protocol (Deere 2005).

Actions identified in an Improvement Action Plan may include:

- Develop asset maintenance and equipment calibration supporting program
 - Disinfect water from all sources
 - Maximise duration and extent of pressurised system through an improvement program
 - Improve sanitary protection and water conservation through improved distribution system asset management
 - Develop consumer education and operator training supporting programs
- Implementing HACCP based Water Safety Plans in urban systems in developing countries would require the following commitments and resources:
- Up to 12 months to create and implement the system
 - Acknowledge that the program will require several years until water quality improvements identified in an Improvement Action Plan are clearly evident
 - Ongoing, active management and maintenance of the Water Safety Plan once it had been implemented
 - A person dedicated to the coordination and active management of the Water Safety Plan, possibly a full time person
 - A strong commitment to Water Safety Plan implementation by the most senior executives in the utility to support implementation

- A commitment to a culture change within the organisation to move to a more accountable, proactive, risk averse and rapidly responsive working approach
- An increase in process performance monitoring to enable even momentary process failures to be rapidly detected, but noting that issues with remoteness and costs may limit such processes.

A number of tools such as the Australian Electronic Decision Support Tool (AEDST) are available to assist with the implementation of Water Safety Plans. AEDST consists of a customised software platform which takes the user through a series of questions. At the end, a draft Water Safety Plan is produced, in MS Word[™] format which includes a simple system description, a flow diagram, a list of possible hazards, suggested control measures and suggestions on operational and verification monitoring. The final output is around 35 pages in length. This tool presents a model which could be tailored to meet requirements of water supply systems in other countries (Deere 2005).

Many community water supply systems in developing countries require significant system improvements to ensure the supply of safe water. In general, community water supplies are managed by communities at their own discretion with only minor involvement from other parties. The inability to apply essential control measures (step 7) will make such small systems ineligible for applying HACCP.

SUMMARY

Relying on water quality test results to ensure the safety of drinking water has serious shortcomings in minimising the impact on customers if a water quality event occurs. The application of HACCP principles in a systematic manner ensures that water quality risks are controlled as close to their sources as possible. Such systems can be easily implemented for most water utilities with supporting programs including basic elements of good management practices and continuous evaluation and audit processes.

Yarra Valley Water has successfully applied HACCP to its water supply system since 1999 and integrated into the Company's normal business practices. Application of HACCP has ensured the effective management of water

quality risks and allowed for the development and implementation of improvement programs to enhance the guarantee of supply of safe water to the customers.

The application of a preventive risk management framework to manage water quality has been recommended by the Australian Drinking Water Guidelines (Australian Government 2004) and the World Health Organisation. Yarra Valley Water's approach in 1999 to apply HACCP to its water supply proved invaluable for the development of its Risk Management Plan in 2005 to comply with the regulatory requirements introduced in the State of Victoria in 2004.

Some developing countries have recently developed active programs to implement the WHO *Guidelines for Drinking Water Quality* (WHO 2004) through use of risk assessment, implementation of Water Safety Plans, and development of a surveillance protocol. These plans are still at their early stages and will be the initial step towards implementing complete HACCP systems over time.

Implementing HACCP based Water Safety Plans in urban systems in developing countries would require a strong commitment from senior executives in the utility to support implementation, a dedicated person to coordinate and actively manage the Water Safety Plan, development of a long term Improvement Action Plan, increase in process performance monitoring and commitment to a culture change within the organisation to move to a more accountable, proactive, risk averse and rapidly responsive working approach.

ACKNOWLEDGEMENTS

The author wishes to acknowledge Yarra Valley Water for its support and encouragement in preparing this paper. Information provided by Dr. Daniel Deere of Water Futures, Australia and the Cooperative Research Centre for Water Quality and Treatment, Australia is greatly appreciated.

REFERENCES

- Anon 2005 Victoria's safe drinking water regulations. *Health Stream* 39, 4–5.

- Australian Government 2004 *Australian Drinking Water Guidelines*. National Health and Medical Research Council, Australia.
- Chapman, T., Jayaratne, A. & Pamminer, F. 2003 *Proceedings of American Water Works Association Annual Conference*. Anaheim, California. AWWA, Denver, CO.
- Codex Alimentarius Commission 1993 *Guidelines for the Application of Hazard Analysis and Critical Control Points (HACCP) System*. Codex, Rome.
- Davison, A. & Deere, D. 2005 Risk management and due diligence in the water industry. *Water* **32**(3), 56–59.
- Deere, D 2005 *Water Safety Frameworks and Risk-Based Water Quality Management for Monsoonal Community and Urban Water Supplies*. Government of Bangladesh Water and Sanitation Sector, Australian Study Tour Report.
- Drinking Water HACCP Plan 1999 Yarra Valley Water, Australia.
- Drinking Water Quality Risk Management Plan* 2005 Yarra Valley Water, Australia.
- WHO 2004 *Guidelines for Drinking Water Quality*. World Health Organisation, Geneva, Switzerland.

First received 2 April 2007; accepted in revised form 13 September 2007. Available online March 2008