Utilization of Hazard Analysis and Critical Control Points Approach for Evaluating Integrity of Treatment Barriers for Reuse

WateReuse Research Foundation

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About the WateReuse Research Foundation

The mission of the WateReuse Research Foundation is to conduct and promote applied research on the reclamation, recycling, reuse, and desalination of water. The Foundation's research advances the science of water reuse and supports communities across the United States and abroad in their efforts to create new sources of high quality water for various uses through reclamation, recycling, reuse, and desalination while protecting public health and the environment.

The Foundation sponsors research on all aspects of water reuse, including emerging chemical contaminants, microbiological agents, treatment technologies, reduction of energy requirements, concentrate management and desalination, public perception and acceptance, economics, and marketing. The Foundation's research informs the public of the safety of reclaimed water and provides water professionals with the tools and knowledge to meet their commitment of providing a reliable, safe product for its intended use.

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Abbreviations and Acronyms

ADWG	Australian Drinking Water Guidelines
AGWR	Australian Guidelines for Water Recycling
AOP	advanced oxidation process (for disinfection consisting of hydrogen peroxide addition and ultraviolet light exposure)
AS OHS	Australian Standards for Occupational Health and Safety
ASP	activated sludge plant
AWPF	advanced water purification facility
AWWA	American Water Works Association
BGA	blue-green algae
BOD	biochemical oxygen demand
CAC	Codex Alimentarius Commission
CCP	critical control point
CCR	California Code of Regulations
CDPH	California Department of Public Health
CT	contact time (for disinfection using chlorine)
CWW	City West Water, Victoria, Australia
DHS	Department of Human Services
DOH	Department of Health
DSE	Department for Sustainability and Environment, Victoria, Australia
DVGW	German Technical and Scientific Association for Gas and Water
EPHC	Environment Protection Heritage Council
ETP	Eastern Treatment Plant, Victoria, Australia
ETV	environmental technology verification
FEMA	Federal Emergency Management Agency
FMECA	failure modes effects and criticality analysis
FSIS	Food Safety and Inspection Services
HACCP	hazard analysis and critical control point
HAZMAT	Hazardous Materials Response Team
HAZOP	hazard and operability
IBWA	International Bottled Water Association
IMS	integrated management system
INCP	incident notification and communication protocol
IRWD	Irvine Ranch Water District
ISO	International Standards Organization
ISQMS	Integrated Sewage Quality Management System
LIMS	laboratory information management system
MF	microfiltration
MSDS	materials safety data sheets
MW	Melbourne Water, Victoria, Australia

MWRP	Michelson Water Reclamation Plant
MWW	Western Treatment Plant, Victoria, Australia
NASA	National Aeronautics and Space Administration
NIMS	National Incident Command System
NRC	National Research Council
NSF	National Standards Foundation
NTU	nephelometric turbidity units
NWRI	National Water Research Institute
O&M	operation and maintenance
OCWD	Orange County Water District
OMMP	operation, maintenance, and monitoring plan
PCS	process control system
PHA	process hazard analysis
PHRMP	Public Health Risk Management Plan
PLC	programmable logic controller
POA	points of attention
PRP	prerequisite programs
PUB	Public Utilities Board, Singapore
QA	quality assurance
QC	quality control
QCP	quality control point
QMRA	quantitative microbial risk assessment
RO	reverse osmosis
RWQCB	Regional Water Quality Control Board
RWQMP	recycled water quality management plan
RWTP	recycled water treatment plant
SCADA	supervisory control and data acquisition
SEMS	Standardized Emergency Management System
SOP	standard operating procedure
SSM	safety and security management
STP	sewage treatment plant
TOC	total organic carbon
UF	ultrafiltration
USEPA	United States Environmental Protection Agency
UV	ultraviolet light
UVT	ultraviolet transmissivity
WHO	World Health Organization
WRMS	water resources management system
WSP	water safety plan
WWTP	wastewater treatment plant

Foreword

The WateReuse Research Foundation, a nonprofit corporation, sponsors research that advances the science of water reclamation, recycling, reuse, and desalination. The Foundation funds projects that meet the water reuse and desalination research needs of water and wastewater agencies and the public. The goal of the Foundation's research is to ensure that water reuse and desalination projects provide sustainable sources of high-quality water, protect public health, and improve the environment.

An Operating Plan guides the Foundation's research program. Under the plan, a research agenda of high-priority topics is maintained. The agenda is developed in cooperation with the water reuse and desalination communities including water professionals, academics, and Foundation subscribers. The Foundation's research focuses on a broad range of water reuse and desalination research topics including:

- Defining and addressing emerging contaminants, including chemicals and pathogens
- Determining effective and efficient treatment technologies to create 'fit for purpose' water
- Understanding public perceptions and increasing acceptance of water reuse
- Enhancing management practices related to direct and indirect potable reuse
- Managing concentrate resulting from desalination and potable reuse operations
- Demonstrating the feasibility and safety of direct potable reuse

The Operating Plan outlines the role of the Foundation's Research Advisory Committee (RAC), Project Advisory Committees (PACs), and Foundation staff. The RAC sets priorities, recommends projects for funding, and provides advice and recommendations on the Foundation's research agenda and other related efforts. PACs are convened for each project to provide technical review and oversight. The Foundation's RAC and PACs consist of experts in their fields and provide the Foundation with an independent review, which ensures the credibility of the Foundation's research results. The Foundation's Project Managers facilitate the efforts of the RAC and PACs and provide overall management of projects.

The focus of this project is to build on the Australian and broader international experience with hazard analysis and critical control points (HACCP) for recycled water management and to help evaluate, pilot test, and tailor a HACCP approach to microbial control in U.S. reclaimed water systems. Although water reclamation in the United States is regulated by individual states, this project will develop a framework based on HACCP principles that could be considered by states for incorporation into their water recycling regulations.

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Executive Summary

It is not practicable to routinely and continuously measure microbial pathogens in treated recycled water to demonstrate that concentrations are continually low enough that the water is safe for common end uses. The hazard analysis and critical control points (HACCP) system was developed as an engineering means of controlling microbial hazards in consumed food. HACCP in its current form for the food sector is described in detail by the United Nations Food and Agriculture Organization/World Health Organization. It is important to note that HACCP has been adopted internationally by a number of countries to manage microbiological and chemical contaminants in water treatment systems, including reclaimed water plants, and yet its use in the water industry in the United States remains limited.

The focal points of this project were to build on Australian and broader international experience with HACCP for recycled water management and help evaluate, pilot test, and tailor a HACCP approach for microbial control in U.S. reclaimed water systems, including consideration of the benefits and disadvantages of adopting a HACCP approach for microbial control of reclaimed water systems. Although water reclamation in the United States is regulated by individual states, templates for three types of reclaimed water systems based on HACCP principles have been proposed for consideration by U.S. states for incorporation into their water recycling regulations (refer to Appendices F–G).

There were several distinct components to this project, including preparation of a comprehensive HACCP literature review, collection and analysis of existing data and case studies (including conducting an international HACCP workshop), conducting a gap analysis (i.e., a comparison study between two existing U.S. treatment plants and a HACCP approach, identifying the overlap and differences in approaches), and conducting U.S. HACCP pilot studies. The gap analysis study was a scope addition that arose from the international HACCP workshop. As a result of the completion of these studies, which were in effect pseudo–pilot trials, conducting additional pilot trials was considered of lesser value than the preparation of HACCP template plans for a variety of different treatment systems. Therefore, the project team was granted a scope change to deliver three HACCP template plans that could be used by U.S. utilities as a starting point to develop their own HACCP systems.

HACCP is typically applied as one part of a broader management framework. Using HACCP efficiently and effectively for the control of microbial hazards within U.S. water reuse schemes would require its integration within these existing frameworks. HACCP could be used to strengthen or fill any gaps within them.

The major adaptation in applying HACCP to the water sector as distinct from a typical food process is the continuity of the essential supply to consumers. Unlike an idealized manufacturing process, the provision of water often needs to be continuous, and the supply cannot always be batched, tested, and shut down for any extended period of time if problems are detected. Furthermore, shutting down a water supply is rarely an option because water supply needs to be maintained for firefighting, sanitation, and other general uses. This makes the monitoring and corrective action procedures more difficult to apply, particularly where there is no alternative water source available. In practice, the same is often true, or partly true, for food, however, and sometimes recalls need to be issued after food has been supplied to the market. Furthermore, the "boil water advisory" (or equivalent) is similar to a product recall or advisory to avoid consumption of certain foods.

Perhaps of more significance is the notable difference in regulatory structure of the United States compared with some countries where HACCP has been widely adopted. For example, Australia adopts a risk-based approach to water treatment, whereby utilities must demonstrate to regulators that they have adequately considered and addressed the risks associated in complying with the Australian Drinking Water Guidelines or Australian Guidelines for Water Recycling. Such a risk-based approach enables flexibility in achieving guideline compliance, facilitating adoption of alternative approaches such as HACCP.

In contrast, the more prescriptive (regulated) approach adopted in the United States does not provide the same degree of flexibility in achieving the desired water quality outcome. For example, in theory the adoption of a HACCP approach should reduce the need for compliance monitoring; however, in the current regulatory environment, this may not be easily achieved. A significant concern expressed at one point during the project by a key stakeholder was that U.S. regulators may insist on a HACCP approach in addition to the current requirements, which would lead to additional cost, duplication of effort, and further inefficiency in the water treatment process. This might be the major concern for small to mid-sized utilities. The validity of that concern was not tested by discussion with regulators, but the perception remains strong in the meantime.

It is important to emphasize that, although adopting a HACCP approach is considered a very good framework for risk management and control in water treatment systems, there are many other systems that achieve the same or similar outcomes. Many well-functioning U.S. treatment plants have invested considerable effort in implementing their own systems that in large part address many of the issues covered as part of a HACCP approach.

This was highlighted during the gap analysis study (refer to Chapter 5) in which two very well-run water treatment plants were examined. The gap analysis established that there are significant differences between the reuse water quality regulatory structures operating in the United States as compared to some other jurisdictions. Within the United States, the approach is currently more prescriptive and end product-driven than the regulations for Australia, Singapore, and some other jurisdictions that use an approach that is more like HACCP, even a literal HACCP approach in some cases.

The underlying objective of introducing HACCP to water reuse within these international jurisdictions was to achieve and assure continuous and reliable end-product water quality through process management to overcome what was seen as the fundamental limitations of a management regime focused primarily on occasional end-product monitoring.

It is perceived that introducing a HACCP approach to U.S. utilities that have an established treatment facility may not offer appreciable benefits because the end-product water quality outcome is so heavily prescribed by the permit issued to each treatment facility by a state regulatory agency. On the basis of the gap analysis, U.S. utilities may believe that HACCP would impose additional regulations, potentially increase costs, and duplicate efforts to achieve the same end-product water quality. The stringent U.S. regulatory requirements for transparency and end-product quality may hinder implementation of the entire HACCP approach, including reporting of process performance deviations and pass/fail certification audits, for most U.S. utilities.

In summary, HACCP was demonstrated to be a useful, good practice, product quality management system tool. The study authors recommend review of and adherence to the intent of the HACCP principles by recycled water scheme operators and managers. Just how literal and formal implementation of HACCP should be depends on the specific circumstances of each jurisdiction and scheme and can be judged on a case-by-case basis. Considerations include the current regulatory context, stage of scheme development, scale of scheme, and utility and quality of existing systematic management systems.

Chapter 1

Introduction

1.1 Project Background

It is not yet practicable to routinely and continuously measure microbial pathogens in treated recycled water to demonstrate that concentrations are continually low enough that the water is safe for common end uses. Most microbiological analytical methods are too slow to report and in any case are not able to detect pathogens at the desired concentrations (i.e., typically less than one organism per tens or even hundreds of liters). The same problem arises in food and drinking water quality control (QC). The hazard analysis and critical control points (HACCP) system was developed as an engineering means of controlling microbial hazards in consumed food.

HACCP in its current form for the food sector is described in detail by the United Nations Food and Agriculture Organization/World Health Organization (WHO; Codex Alimentarius Commission [CAC], 2003) in International Standards Organization (ISO) 22000 (2005) and National Advisory Committee on Microbiological Criteria for Foods (1997). A full description, including the history of HACCP, is articulated in Chapter 2. It is important to note that HACCP has been adopted by a number of countries to manage microbiological and chemical contaminants in water treatment systems, including reclaimed water plants, and yet its use in the water industry in the United States remains limited.

The focal points of this project are to build on Australian and broader international experience with HACCP for recycled water management and help evaluate, pilot test, and tailor a HACCP approach to microbial control in U.S. reclaimed water systems. Although water reclamation in the United States is regulated by individual states, this project will develop a framework based on HACCP principles that could be considered by states for incorporation into their water recycling regulations.

1.2 Technical Approach

There were several distinct components to this project, including preparation of a comprehensive HACCP literature review, collection and analysis of existing data and case studies (including conducting an international HACCP workshop), conducting a gap analysis (i.e., a comparison study between two existing U.S. treatment plants and a HACCP approach, identifying the overlap and gaps in approaches), and conducting U.S. HACCP pilot studies.

The gap analysis study was a scope addition that arose from the international HACCP workshop. This study explored the differences in approach between a HACCP system and two existing U.S. treatment plant operations. As a result of these studies, which were in effect a form of pseudo–pilot trial, the need to conduct additional pilot trials was of lesser value than the preparation of HACCP template plans for a variety of different treatment systems. Therefore, the project team was granted a scope change to deliver three template plans that could be used by U.S. utilities as a starting point for developing their own HACCP systems.

An outline of the technical approach is provided in the following. The conclusions and recommendations are provided in Chapter 7.

1.2.1 Literature Review

The literature review was undertaken as a series of tasks, which included:

- Collate, review, and synthesize previous HACCP studies for process control in water. This included previous studies by the project proponents (e.g., the American Water Works Association Research Foundation–United States Environmental Protection Agency [USEPA] funded project developing a tailored HACCP approach for water supplies [Martel et al., 2006]) and studies from the broader literature (Chapter 2).
- Document the evolution and use of HACCP and systems incorporating HACCP principles in the Australian water industry, also noting selected Western European (e.g., Switzerland, France, and Iceland) and Southeast Asian (e.g., Singapore and Chinese economic development areas) experiences. Many of these regions have widespread use of certified HACCP plans as well as approaches that wholly incorporate the HACCP preliminary steps and systems into their risk management frameworks (Chapter 2).
- Document the current status of HACCP and systems incorporating HACCP principles in the U.S. water industry (Chapter 3).
- Document the probable reasons for not using HACCP for regulation within the United States (Chapters 2 and 7).

The literature review provided a broad evidence base to understand and comment on the practical application of HACCP. The review was completed in two parts and is discussed in Chapters 2 and 3.

1.2.2 Data Collection and Case Studies

1.2.2.1 HACCP Plans and Case Studies

A total of eight documented HACCP plans currently in operation were collated and analyzed for reclaimed water systems. These plans covered a range of water uses, including:

- indirect potable and industrial reuse
- so-called dual reticulation or third-pipe systems (with an independent recycled water reticulation network to each property in addition to the potable water network)
- irrigation of food crops
- public open space irrigation

Participating utilities either provided their entire HACCP plan or selected extracts to enable an analysis and comparison of approaches. The HACCP plans (and HACCP-based plans) were summarized with respect to pertinent high level factors such as:

- drivers to implement
- time to implement
- costs to implement and maintain
- benefits of implementation
- regulatory versus voluntary status
- barriers to implementation
- other perspectives worth sharing

In addition, the HACCP and HACCP-based plans were summarized with respect to pertinent, detailed aspects including:

- high risks identified
- controls identified
- designation of critical control points (CCP)
- critical limit monitoring parameters and values
- validation evidence base
- verification requirements
- prerequisite programs (PRPs) or sanitation standard operating procedure (SOP) equivalents
- supporting programs identified

The full details and analysis of this work are included in Chapter 4.

1.2.2.2 International HACCP Workshop

An international peer consensus workshop on HACCP for microbial protection in reclaimed water schemes was convened to understand and explore the international experience, including the benefits and disadvantages of adopting a HACCP approach. The workshop agenda and summary notes are outlined in Chapter 4 and Appendix A.

1.2.3 Gap Analysis

Following an international workshop on HACCP, convened at Orange County Water District (OCWD) in California) in September 2010 by the project team (refer to Appendix A), a need arose to conduct one or more gap analyses to compare existing recycled water facilities against HACCP requirements and supporting programs with respect to overall quality management, including but not limited to recycled water quality and microbial control. The results of this work have been outlined in Chapter 5.

1.2.4 Preparation of HACCP Template Plans

HACCP template plans were completed to cover a range of reclaimed water systems, water types, and water qualities. Three schemes were addressed in total, including advanced treated reclaimed water (for indirect potable reuse), disinfected tertiary reclaimed water, and disinfected secondary reclaimed water. The HACCP template plans are discussed in Chapter 6, and the template plans are included in Appendices F through H.

Chapter 2

International Literature Review—Part A

2.1 What Is HACCP?

The term HACCP is usually pronounced phonetically as “hass up.” It is a logical, scientific process control system (PCS) designed to identify, evaluate, and control hazards that are significant for food safety. In general, the scope of HACCP is extended beyond just safety to cover other aspects that affect the suitability of a food for consumption (e.g., so-called wholesomeness, including taste, appearance, odor, and customer acceptability).

The purpose of a HACCP system is to put in place process controls that will detect and correct deviations in quality processes at the earliest possible opportunity. Early detection and correction help to reduce the wastage associated with end-of-line testing of batched products. In addition, and of more relevance to the water sector, early detection and correction prevent consumers from receiving unfit products where the supply of the product is continuous and end-of-line testing can only detect problems after consumption or use of the product has already occurred.

Development of HACCP began in 1959 as part of the U.S. space program. National Aeronautics and Space Administration (NASA) was planning manned space missions and needed to address concerns about contamination of the astronauts’ food from “potentially catastrophic disease producing bacteria and toxin” (NASA, 1991). NASA sought assistance from the Pillsbury Company to develop the HACCP concept “to establish control over the entire process, the raw materials, the processing environment and the people involved” (NASA, 1991). The Pillsbury Company developed the basic HACCP concepts with cooperation and participation from NASA, the Natick Laboratories of the U.S. Army, and the U.S. Air Force Space Laboratory Project Group (Mucklow, 1997).

Since the 1980s, the HACCP system has been internationally adopted by the food and beverage industries and forms an important part of their food safety plans or programs. Quality assurance (QA) systems incorporating HACCP principles have become the benchmark for assuring food and beverage safety since the codification of HACCP in 1993 by WHO (Deere and Davison, 1999).

In 1996, the U.S. Food and Drug Administration (FDA) and Department of Agriculture, Food Safety and Inspection Service (FSIS), promulgated regulations requiring the use of HACCP in the seafood, red meat, and poultry industries. Since that time, the use of HACCP within the U.S. food industry has become ubiquitous.

The WHO guidelines for HACCP, Codex Alimentarius, have been adopted internationally as the primary recognized food safety methodology for risk management. The most current HACCP guideline (rev. 4) was developed in 2003 by CAC (2003).

In 2005, the ISO 22000 standard, Food Safety Management Systems—Requirements for any organization in the food chain, was released (ISO, 2005). ISO 22000 is in effect an ISO version of HACCP and starting to supersede the Codex HACCP in many contexts. ISO 22000 is somewhat broader; it includes many of the supporting programs that were implicit but not explicit in Codex HACCP.

By helping to improve food production processes to prevent contamination, the HACCP system can reduce or prevent the occurrence of food-borne illnesses. In October 2003, the United States Department of Agriculture/FSIS reported four consecutive annual drops in human *Listeria* infection and a 70% decline in positive food samples compared with years prior to HACCP implementation (Fok and Emde, 2004).

2.2 The HACCP Steps

The CAC defines 12 sequential steps (or 5 preliminary steps and 7 principles) for planning and implementing a HACCP system (CAC, 2003). The information prepared in completing these 12 steps constitutes the utility's HACCP plan. These 12 tasks follow a logical and structured sequence to develop the HACCP plan, as follows:

2.2.1 Preliminary Steps

- Step 1: Assemble a HACCP team. Pull together a multidisciplinary team to plan, develop, verify, and implement the plan.
- Step 2: Describe the product. Describe the product, in this case recycled water, including its source, treatment, storage, distribution, and any existing standards for product safety.
- Step 3: Identify intended use. Describe how the product is used and the major users.
- Step 4: Construct a flow diagram. For a comprehensive HACCP plan, this would be a schematic showing sources of water, details of treatment, storage, pumping, and distribution to end users. For a HACCP plan directed toward a distribution system, the schematic would be restricted to showing the water flow path from the treatment plant to end users.
- Step 5: Validate process flow diagram. As a critical element around which the HACCP is based, the flow diagram needs confirmation of accuracy by the HACCP team.

2.2.2 HACCP Principles

- Step 6: Conduct hazard analysis. Using the process flow diagram, identify hazards, their likelihood of occurrence, potential consequences, and control measures.
- Step 7: Identify CCP. For each significant hazard, identify points in the process where the consequences of failure are irreversible.
- Step 8: Establish critical limits. Determine critical limits for the CCP that will trigger a corrective action. A critical limit is a criterion that separates acceptability from unacceptability.
- Step 9: Identify monitoring procedures. Establish monitoring points, frequency, and responsibility.
- Step 10: Establish corrective action procedures. Develop plans for follow-up activity when critical limits are exceeded.

- Step 11: Validate or verify HACCP plan. Have the HACCP team and other affected parties check the HACCP plan for accuracy, implementability, and potential effectiveness.
- Step 12: Establish documentation and recordkeeping. Develop a recordkeeping system to track system performance at CCPs.

In practice, HACCP is normally applied along the lines set out in ISO 22000 but in a broader context. In fact, most HACCP certification bodies have requirements to include more than merely the 12 steps to achieve HACCP certification. The practical application of HACCP to reuse in the water sector would typically involve a documentation and system structure something like that given in Figure 2.1 and include four major components:

- Recycled water quality management framework
- Recycled Water Quality Management Plan (RWQMP)
- Supporting programs
- HACCP plan

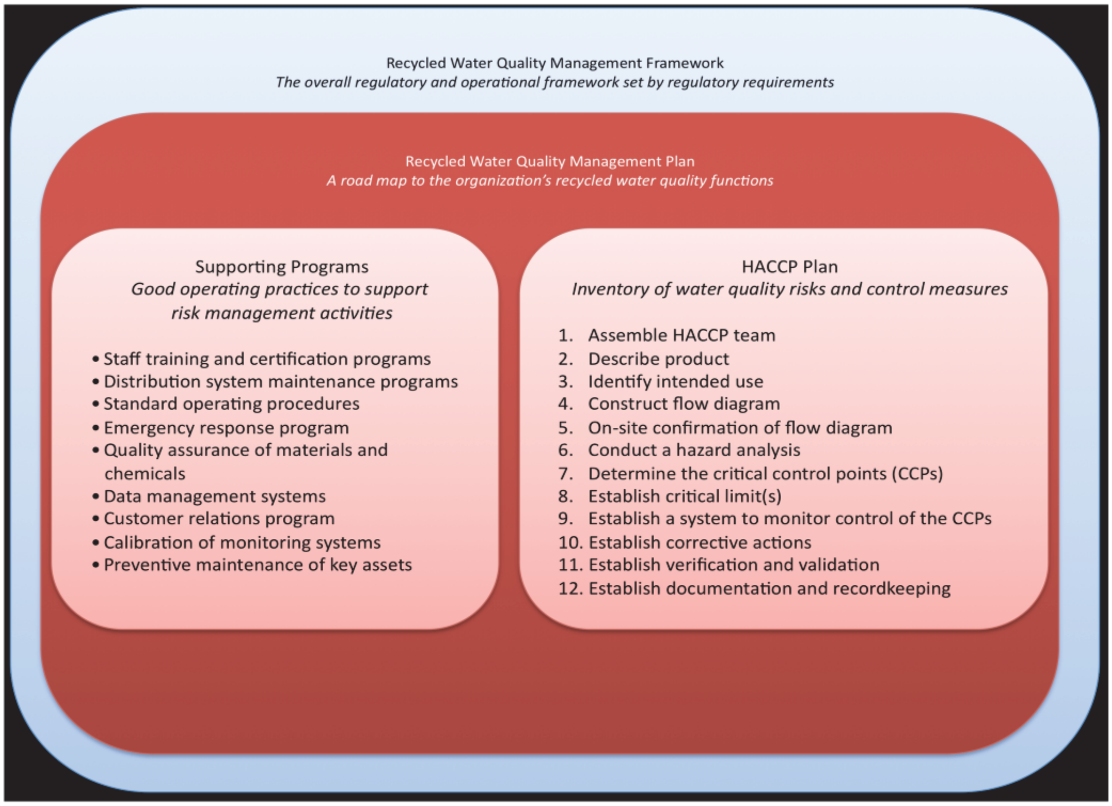


Figure 2.1. Overview of HACCP in the broader context illustrating the importance of other programs and processes

Source: Based on Martel et al., 2006

2.3 HACCP Application to the Water Sector

One advantage of applying HACCP to water supply safety management comes from its ubiquitous international use in assessing and controlling food safety risks. This bestows on the system international familiarity and acceptance among food safety regulators and professionals who, in many cases, also regulate and deal with the consumer safety aspects of water supplies. It also provides a tested framework on which to base a water sector model of HACCP.

On the other hand, one of the limitations of the default HACCP guidelines is that they have been tailored to food application. This is not a major difficulty because the concepts are clearly transferable, but there is scope for producing a tailored HACCP model for the water sector. Such tailored models are very common. There are a variety of different types of foods, and industry associations have worked to develop generic HACCP plans and guidelines for their industry members. Of some relevance to reuse are the bottled water HACCP plans developed by the International Bottled Water Association (IBWA) and the seafood HACCP plans developed by the U.S. Food and Drug Administration (FDA).

2.3.1 Bottled Water

HACCP has been applied to all types of water. In many countries reticulated potable water is also regulated as a food. In the United States, the most logical application of HACCP to water is in relation to bottled water because it is regulated and managed as a food. At the federal level, bottled water is regulated as a packaged food product governed by the FDA through the Food, Drug, and Cosmetic Act. At the state level, bottled water is regulated in a myriad of ways, typically through state environmental, food, or agricultural agencies.

The bottled water industry typically applies the HACCP approach to help ensure the safety and quality of its product from source through treatment and distribution and even to the packaging materials that are used. For instance, members of the IBWA must adhere to the IBWA Model Code (IBWA, 2012) , which requires a HACCP program for each facility. The IBWA Model Code is typically more stringent than the state and federal regulations that apply, although some states use the Model Code as their standard for regulation of bottled water.

2.3.2 Tap Water

2.3.2.1 Proof of Concept

Bryan (1993) in the United States and Havelaar (1994) in the Netherlands first published the concept of applying HACCP to drinking water systems. Bryan presented the HACCP approach as a way to improve water treatment processes to reduce the occurrence of waterborne disease. He also noted the need to address distribution system inadequacies (e.g., ingress from contaminated surface water or sewage if the distribution system is poorly maintained and bacterial regrowth within the distribution system) that could affect the quality of finished water.

Havelaar (1994) reviewed the applicability of HACCP to drinking water supply with a focus on microbial contaminants. He introduced a generalized HACCP analysis for drinking water production, including source, treatment, and distribution process steps, listing typical hazards, preventive measures, CCPs, monitoring procedures, and corrective actions (refer to Tables 2.1–2.3). Havelaar went on to consider the integration of quantitative microbial risk assessment (QMRA) with HACCP. QMRA in this context was proposed as a tool for setting targets for microbial control at key process steps.

Table 2.1. Summary of the Application of HACCP to Potable Water Supply Catchments

Hazards	Preventive Measures	CCP	CCP Parameters	Monitoring Procedures	Corrective Actions
Process Step: Groundwater Abstraction					
Transport of pathogens to wellhead	Define protection zone around well and restrict land use	Yes	Traveling time	Tracer injection studies, specific pathogens, fecal index bacteria	Remove sources of pollution
Ingress of pathogens through well casing	Proper construction and maintenance	Yes	Adhere to good engineering practices	Inspection, fecal index bacteria	Instruction, reconstruction
Process Step: Bank Infiltration					
Transport of pathogens to wellhead	Define minimum travelling time, distance, or both.	Yes	Site-specific	Tracer injection studies, specific pathogens, fecal index bacteria	Replace abstraction wells, increase treatment
Ingress of pathogens through well casing	Proper construction and maintenance	Yes	Adhere to good engineering practices	Inspection, fecal index bacteria	Instruction, reconstruction
Process Step: Surface Water Abstraction					
Contamination by fecal discharges	Reduce point and diffuse pollution sources	No		Fecal index bacteria, specific pathogens, turbidity	Increase treatment
Multiplication of pathogens	Control eutrophication -thermal discharges, residence time of water	No		Not applicable	
Process Step: Storage and Surface Water in Reservoirs					
Short-circuiting	Build reservoirs in series	No		Tracer studies, conservative parameters, fecal index bacteria	Increase treatment
Recontamination by wildlife feces	Discourage presence of wildlife	No		Specific pathogens	

Source: Adapted from Havelaar, 1994
Note: CCP=critical control point

Table 2.2. Summary of the Application of HACCP to Potable Water Treatment

Hazards	Preventive Measures	CCP	CCP Parameters	Monitoring Procedures	Corrective Actions
Process Steps: Pretreatment, Coagulation, Flocculation, Sedimentation, Filtration					
Poor floc formation, poor floc removal, filter defects with reduced pathogen removal	Increase coagulant dose, add coagulant aid, regular backwashing and cleaning, first filtrate after backwash to waste	Yes	Turbidity, particle counts, pressure loss	Online monitoring	Increase disinfection
Process Step: Disinfection					
Survival of pathogens	Optimize dose and CT of disinfectant	Yes	Residual concentration of disinfectant (may vary during the year), pH, temperature, bacteriological indicator organisms	Online monitoring	Automatic feedback system
Formation of disinfection by-products	--	--	--	--	Modify target dose or residual

Source: Adapted from Havelaar, 1994

Notes: CCP=critical control point; CT=contact time

Table 2.3. Summary of the Application of HACCP to Potable Water Distribution

Hazards	Preventive Measures	CCP	CCP Parameters	Monitoring Procedures	Corrective Actions
Contamination from cross-connections and storage facilities	Adequate construction; positive pressure at all times	Yes	Total coliform bacteria, system pressure, disinfectant residual	Frequent samples; testing of backflow prevention devices	Isolate part of system; rechlorinate
Contamination at repair and construction sites	Sanitary practices during construction and repair	Yes	Adhere to sanitary practices	Inspection, sample	Flushing, disinfection, worker training, program assessment
Regrowth of opportunistic pathogens	Reduce residence time; reduce AOC and biofilm potential	Possibly, system dependent	Disinfectant residual, total coliform bacteria, AOC, water temperature	Frequent monitoring	Flushing, disinfection, treatment optimization, reducing water age

Source: Adapted from Havelaar, 1994.

Note: AOC=area of contamination; CCP=critical control point

2.3.2.2 Practical Implementation

Practical HACCP implementation in urban water systems has advanced over the last 15 years, in some cases led by utilities and in other cases by utilities responding to guidelines and regulations developed by regulatory bodies.

WHO commissioned a review of the conceptual application of HACCP to water supply (Havelaar, 1994). Many of the HACCP concepts were then elaborated, albeit not termed HACCP, by the third volume of the second edition of the WHO Guidelines for Drinking Water Quality in 1997. Much of the HACCP terminology is explicitly used within the current (fourth) edition of WHO Guidelines for Drinking Water Quality (2011), as was the case with the third edition (2004).

Since 2004, the WHO guidelines have included the Water Safety Plan (WSP; WHO, 2009) approach to water quality and risk management. The WSP is broadly analogous to and explicitly based on HACCP but applied within the context of a broader framework. The WHO framework has three main components:

- Health-based water quality targets based on public health protection and disease prevention
- A WSP, which is similar to a HACCP plan, as noted previously
- Independent surveillance activities including audits of the WSP and final checks on the finished drinking water

WHO recommends that water suppliers develop a WSP that documents the following major elements:

- source-to-tap system assessment that determines whether a water system can deliver water meeting certain quality targets
- operational monitoring of control measures for identified hazards—a management plan that documents the system assessment, control measures, monitoring plan, corrective action procedures to address water quality incidents, communication plan, and supporting programs such as SOP, employee training, and risk communication

An early practical application of HACCP in the United States was that of a Californian watershed (Barry et al., 1998, 2004). HACCP was applied to the control of *Cryptosporidium* from cattle and pigs in the Alameda Creek watershed.

HACCP has been widely applied in Australasia. The HACCP preliminary steps, principles, and many of the supporting programs are applied within the Public Health Risk Management Plan (PHRMP) requirements of Drinking-Water Standards New Zealand (Ministry of Health 2008) and the Framework for Management of Drinking Water Quality in the Australian Drinking Water Guidelines (ADWG; Cunliffe, 2001, 2004; National Health and Medical Research Council /Natural Resource Management Ministerial Council, 2004). Within Australia, system-specific HACCP plans have been developed and certified. Since the mid-1990s, HACCP has been applied by several water utilities in Australia that have independently audited, certified HACCP systems for potable water supply, including South East Water in Melbourne (Deere, personal communication, 2010), Yarra Valley Water in Melbourne (Jayaratne, 2008; Chapman, 2003), Melbourne Water (Hellier, 2003), Brisbane City Council (Gray and Morain, 2000), and Gold Coast Water (now Allconnex Water; Smith, personal communication, 2010).

Within Europe, the objective of the Council Directive (98/83/EC) on the quality of water intended for human consumption is to protect human health from the adverse effects of any contamination of water intended for human consumption by ensuring that it is wholesome and clean (European Council, 1998). Directive 98/83/EC does not include provisions for a WSP; however, there is an ongoing project (Support for the Development of a Framework for the Implementation of WSPs in the European Union) funded by the European Commission, which will support the planned revision of the Drinking Water Directive, with an expectation of including WSPs (WHO, 2007).

In Switzerland, Article 11 of the hygiene regulation (SR 817.051, HyV) has required the application of HACCP principles since 1995. A regulatory guideline (W1002) entitled Recommendations for a Simple Quality Assurance System for Water Supplies has been prepared to assist water utilities in complying with this requirement. HACCP (and similar system) implementation has been reported from Switzerland (Bosshardt, 2003; Kamm, 2006).

In France, Article 18-2, Optimization of Monitoring, of the French National Transcription: Decree 2001-1220 (Decree 20, 2001), entitled Water Safety for Human Health, Risk Assessment and Management, requires risk assessment, identification of CCPs, and control measures (Metge 2003). Of relevance is the *Loi sur l'eau* (Water Law) of January 3, 1992, and the *Loi sur l'eau et les milieux aquatiques* (Water and Aquatic Environment Law) of December 30, 2006, with the latter transposing the EU Water Framework Directive (European Council, 2000) into French law.

In Iceland, Icelandic waterworks first began implementing HACCP as a preventive approach for water safety management in 1997. Reykjavik Energy has been using an accredited HACCP system for potable water supply since 1997 (Gissurarson, 2004), and many Icelandic water supply systems are HACCP certified. Since then, implementation has been ongoing, and currently more than 70% of the Icelandic population source drinking water from waterworks with a certified HACCP system.

Some of the waterworks that have implemented HACCP have undertaken preliminary evaluation, which has revealed that compliance with drinking water quality standards improved considerably following the implementation. The study revealed some limitations for some, but not all, waterworks in relation to inadequate external and internal auditing and a lack of oversight by health authorities (Gunnarsdóttir, 2008). HACCP implementation has also been reported in the Netherlands (Hein et al., 2006).

In Canada, the Canadian risk assessment approach is intended to outline a simple protocol based on HACCP and other risk assessment/risk management approaches for managers of all drinking water systems to follow. It can be used in conjunction with existing formalized management processes (HACCP, ISO, WSPs) that address large complex systems or equally can be applied to small systems or one aspect or feature of any drinking water system (Canadian Water and Wastewater Association, 2005). The Canadian Guidance Document for Managing Drinking Water Systems states, “These standards and management systems, however, require considerable training, costs, and may be too sophisticated for the small, remote, or non-municipal systems” (Canadian Water and Wastewater Association, 2005). The document further states that the identified method does not assist the operator in determining crucial monitoring and control points in the system from source through treatment through distribution to the user's tap, and that a HACCP method would be warranted for use in Canada for this purpose.

In Ontario, Canada, municipalities and cities are developing and implementing an integrated risk management system based on ISO 9001, ISO 14001, and HACCP (Kuslikis and White, 2004). The Capitol Health region in Edmonton, Canada, used HACCP principles to develop a new boil water advisory protocol in 1998: “The use of the HACCP process resulted in a better understanding of monitoring parameters and fostered communication and understanding between… [the health department and the water utility]” (Fok and Emde, 2004).

In Singapore, the Four National Taps (local catchment, imported water, NEWater, and desalinated water) require WSPs with HACCP certification for both traditional source waters and reclaimed water supplies. The Environmental Public Health (Quality of Piped Drinking Water) Regulations (EPH, 2008) require that every supplier shall prepare and implement a WSP and a water sampling plan for the purpose of ensuring that the piped drinking water being supplied complies with the standards specified. In addition, every supplier shall, at least once a year, conduct a review of the WSP. Singapore currently has five NEWater plants, with the fifth and largest planted located at the Changi Water Reclamation Plant. Together, they supply 30% of Singapore’s current water needs (Singapore Public Utilities Board [PUB], 2010).

Within the United States, the American Water Works Association (AWWA) Research Foundation and U.S. Environmental Protection Agency (USEPA) jointly funded a project considering the application of HACCP for distribution system protection. This study concluded that the implementation of HACCP to water distribution systems was feasible and practical, but the time and resource requirements were greater than originally anticipated by the four pilot utilities involved in the study. For very small utilities, supplying less than 1 MGD of water, with only a small full-time staff, developing and implementing a full HACCP system was not achievable given competing position requirements. This revealed a fundamental difficulty in the implementation of HACCP or, for that matter, any systematic management system, within very small utilities. Recommended changes that may enable implementation for small utilities included:

- Increase the number of employees on staff to provide a critical mass.
- Provide temporary, contracted support for long enough to implement the system funded by a third party, if required.
- Provide generic HACCP plans and guidance combined with very explicit guidance, support, and tools to help utilities implement the systems in practice.
- Provide more support from the state or regional regulatory and support organizations (Martel et al., 2006).

It was further concluded that, for larger utilities, there were sufficient resources to implement HACCP, although there was a requirement to have some personnel reasonably dedicated to implementation. It is important to note that the preparation of the HACCP plan as a document was relatively less resource consuming than the effort required to create a functional HACCP system. The latter requires implementation of actions across the organization.

Martel et al. (2006) states that all participating utilities concluded that their participation in the HACCP process was a valuable one. The development of the HACCP plan was useful in prioritizing risks and process controls for water quality management. The utilities provided evaluation of the HACCP process; Martel et al. (2006) listed the following findings as the most important:

- Most utilities that have gained HACCP certification have done so after some core management systems (e.g., ISO 9001, ISO 14001) had been developed and implemented. These management systems helped the utility to gain management control of people and processes, which made implementing HACCP relatively straightforward.
- In practice, the case study utilities did not operate multiple quality management systems for occupational safety, water quality, and environmental considerations. Although separately identifiable and auditable, in operation all of these systems were captured within an integrated management system (IMS). The principal benefit of an IMS, as identified by water utilities, was the avoidance of duplication, leading to reduced staff time and costs and improved process integration.
- Water quality improvements became evident following the implementation of HACCP, but in most cases those changes did not appear conclusive until after three or more years, when a consistent pattern of improvement emerged. Water quality improvement included a reduced number of customer complaints, water quality incidents, and microbial indicators.
- All utilities that had implemented HACCP and attained certification continued to be audited and registered each year because all believed that, overall, the benefits of the HACCP system, including the certification discipline, outweighed the cost.

- Auditing, though sometimes uncomfortable for operating staff, is a necessary and useful element of HACCP. It forces periodic reviews and keeps utility staff and management up to date on important issues.

Smaller systems have applied HACCP principles too, such as the councils in the Australian state of New South Wales and small suppliers in New Zealand and Iceland (termed mini-HACCP in the latter).

2.3.3 Recycled Water

2.3.3.1 Proof of Concept

The U.S. National Research Council (NRC) considered the viability of augmenting drinking water supplies with reclaimed water (NRC, 1998) and concluded that planned, indirect potable reuse was a viable application of reclaimed water, but only when there was a careful, thorough, project-specific assessment that included contaminant monitoring, health and safety testing, and system reliability evaluation. Further, potable reuse projects should include multiple, independent barriers that address a broad spectrum of microbial and organic chemical containments. The text explicitly recommended the use of HACCP as a tool in potable reuse risk management.

Another published account of the use of HACCP for potable reuse was from a study in Belgium by Dewettinck et al. (2001). The project involved the application of HAACP for the integration of treated domestic wastewater into the existing potable water production process to ensure a sustainable water catchment in the dune area of the Flemish west coast. Taking into account the literature data on the removal efficiencies of the proposed advanced treatment steps with regard to enteric viruses and protozoa, and after setting high quality limits based on recent progress in quantitative risk assessment, the CCP and what the authors termed points of attention (POA) were identified. Based on the HACCP analysis, a specific monitoring strategy was developed that focused on the control of these CCPs and POAs (Dewettinck et al., 2001). The paper concluded by stating that “the whole of this HACCP approach should guarantee safe water reuse, technically and also be psychologically acceptable to the general public” (Dewettinck et al., 2001).

2.3.3.2 Practical Implementation

In Australia, HACCP steps, principles, and supporting programs have been incorporated within the Framework for Management and Use of Recycled Water in the national Australian Guidelines for Water Recycling (AGWR) series: Managing Health and Environmental Risks, Phase 1 (NRMMC, 2006); Phase 2 Augmentation of Drinking Water Supplies (Environmental Protection Heritage Council [EPHC], 2008); Phase 2 Stormwater Harvesting and Reuse (EPHC, 2009). The Australian guidelines cover potable and nonpotable reuse and include stormwater, graywater, and sewage as sources. The guidelines are gradually being mirrored in state-based regulations. In most jurisdictions it is necessary to produce a Recycled Water Quality Management Plan (RWQMP) or similar document, which would have to include a comprehensive HACCP plan for submission to the regulator for scheme approval.

Many Australian utilities now have either HACCP or ISO 22000 certified systems in place for their water reuse schemes. A wide variety of reuse schemes have now been covered by such explicitly HACCP systems or by audited, regulated systems that fully incorporate the HACCP principles into the RWQMP.

Melbourne Water Corporation completed the development of a certified HACCP plan for the Werribee Irrigation District recycled water scheme in 2005. The scheme irrigates food crops to be eaten raw, and the explicit use of the HACCP term was considered to be a factor in encouraging public acceptance of the water by growers and grocery retailers (Smith, 2010, personal communication). More recently, ISO 22000 was applied to the trade waste and sewage source quality management system in place across the city of Melbourne in order to improve, among other things, the control of recycled water quality (Smith, personal communication, 2010).

A HACCP plan has been developed for the indirect potable reuse scheme that will supply Brisbane during major droughts (Roux, personal communication, 2010). The use of the HACCP system was a key component of gaining regulatory approval for the scheme. The HACCP system covers trade waste, sewage source, sewage treatment, and advanced water treatment components of the scheme. Singapore's PUB has used HACCP as part of its QA system for its water supplies, and included within this are its indirect potable reuse schemes and stormwater recycling schemes (Seah, personal communication, 2010).

A summary of current reuse schemes with HACCP plans or those that wholly incorporate all aspects of HACCP is given in Table 2.4.

Table 2.4. Practical Examples of the Application of HACCP to Reuse

Utility and Location of Scheme	Use of Water	Scale of Scheme	System(s) in Place	Date System Externally Accredited or Certified	Source
4 water utilities, Melbourne, Victoria, Australia: South East Water CWW Yarra Valley Water Melbourne Water	Wastewater source control for the whole sewerage system, including trade waste	800–1000 ML/d	ISO 22000 ISO 9001 ISO 14001	2008	HACCP plans supplied by David Smith from South East Water Australia in 2010
Werribee Irrigation District, Melbourne Water, Melbourne, Victoria, Australia	Irrigation of food crops to be eaten raw, water used for outdoor irrigation in technology and tourist precinct	75 ML/d	HACCP ISO 14001 ISO 22000 and ISO 9001	2005; regulatory approval 2005 by DOH and EPA	HACCP plans supplied by Judy Blackbeard from Melbourne Water Australia in 2010
ETP/TopAq system, South East Water, Melbourne, Victoria, Australia	Dual reticulation (Class A)	1.3 ML/d	HACCP ISO 9001 ISO 14001 Health and Environmental Management Plan and RWQMP under Victoria regulations RWQMP under Victoria regulations		

Table 2.4. Practical Examples of the Application of HACCP to Reuse — *continued*

Utility and Location of Scheme	Use of Water	Scale of Scheme	System(s) in Place	Date System Externally Accredited or Certified	Source
ETP/TopAq system, South East Water, Melbourne, Victoria, Australia	Dual reticulation (Class A)	1.3 ML/d	HACCP ISO 9001 ISO 14001 Health and Environmental Management Plan and RWQMP under Victoria regulations	2011	HACCP plans supplied by David Smith from South East Water Australia in 2010
ETP Outfall, South East Water, Melbourne, Victoria, Australia	Irrigation (Class C)	9 ML/d	HACCP	2011	
Pimpama-Coomera, Allconnex Water, Gold Coast, Queensland, Australia	Dual reticulation	8 ML/d	HACCP ISO 9001 ISO 14001 Recycled Water Management Plan under Queensland regulations	2011 2009 2009 2009	HACCP plans supplied by Shannon McBride from Allconnex Australia in 2010
Boneo STP, South East Water, Melbourne, Victoria, Australia	plant uses (Class A)	6 ML/d	HACCP	2009	
Aurora, Yarra Valley Water, Melbourne, Victoria, Australia	dual reticulation and filling station	4 ML/d	HACCP ISO 9001 ISO 14001 Health and Environmental Management Plan and RWQMP under Victoria regulations	To be confirmed	HACCP plans supplied by Asoka Jayaratne from Yarra Valley Water Australia in 2010
Western Corridor, WaterSecure, Brisbane, Queensland, Australia	Irrigation Standby potable reuse	60 ML/d	HACCP Recycled Water Management Plan under Queensland regulations	2009 pending	HACCP plans supplied by Annalie Roux from WaterSecure Australia in 2010
CWW, Melbourne, Victoria, Australia	Municipal with uncontrolled public access (irrigation of parks and sports grounds) Dual reticulation (toilet flushing) Commercial (washdown of animal enclosures, open space irritation) Industrial use (pump gland lubrication, dust suppression, washdown water)	400 ML/yr	HACCP	2010	HACCP plans supplied by Kris Fumberger from City West Water Australia in 2010

Notes: CWW=City West Water; DOH=Department of Health; EPA=Environmental Protection Agency; ETP=Eastern Treatment Plant, Victoria, Australia; HACCP=hazard analysis and critical control points; ISO=International Standards Organization; PUB=Public Utilities Board, Singapore; STP=sewage treatment plant

2.4 Broader Concept of HACCP

The water sector operates within a very broad regulatory and operational framework that collectively contributes to and controls the safety and quality of water supplied. Regulators set standards. Water supply agencies operate the bulk of the systems, often by appointing contractors. Therefore, it needs to be recognized that in practice HACCP is applied within a broader framework of working parts that together control and manage water quality, as shown in Figure 2.1.

Even within the food sector, HACCP is clearly and explicitly only intended to be applied within the context of supporting programs or prerequisite programs (PRPs) through a Food Safety Plan or Food Safety Program. Therefore, a HACCP plan is, in fact, just one element of an overall program for ensuring the delivery of safe, quality water.

Note that although the terms supporting and prerequisite appear to be synonymous and used interchangeably, the use of prerequisite is gaining favor in the food sector, possibly because it emphasizes the genuine importance of these programs. For instance, the ISO 22000 standard adopted the term Prerequisite Programs. Supporting implies that programs are subordinate, which is not the intent. Prerequisite correctly implies that these programs are essential and no less important than the HACCP plan. Furthermore, it is considered preferable in the food sector to have PRPs in place before embarking on the development of the HACCP plan. However, there has been a preference in the water sector to use the term supporting programs (Deere et al., 2001; WHO, 2004).

Typically, HACCP is implemented along with an independent third party audit to gain and maintain some form of recognized certification. The use of certified HACCP systems can give confidence and a certain assurance to customers, as well as regulators, regarding the safety and quality of water being supplied.

2.4.1 QA Systems

The basis of any risk management system is risk recognition and control. An inability to adequately identify risk means that a risk management program will be flawed. Conversely, completely identifying risk but not being able to control people, processes, and systems means that risks are left uncontrolled.

The first important development in control systems came with the development of the concept of QA. The use of QA involves a focus on controlling systems of production or service delivery to ensure that a product is consistently of an appropriate standard.

The complement of QA is quality control (QC), which includes assessing quality by analysis of the end product. QC has not become less important; there is still a need to check things and reject those that don’t comply; however, the objective of QA is to minimize the risk of QC failure, thus reducing costs.

Application of QA principles is particularly valuable for water supply because it is very hard to manage the QC of water between release from storage and the point of consumption or use. It is possible, however, to exact control over the transfer of water from post-treatment storage to the customer to be confident that the water is safe.

QA systems evolved rapidly after World War II in response to the realization that many explosives were not exploding in the field. It's not practical to perform QC on explosive devices—once they've been tested, they're literally blown away. QA systems found their way into production and, more recently service delivery, processes across the developed world.

There are a number of QA standards and guidelines available, with ISO 9001:2008 being the international standard commonly applied in Europe and Australasia (EPA, 2007). In the U.S. water industry, the QualServe programs are currently being implemented. In some countries, the expectation for appropriate QA in the water industry is so strong that many utilities will not award contracts to firms that do not have a formal accreditation to an appropriate ISO standard.

ISO systems are now commonly applied in the global water sector, particularly by the larger contracting companies that provide services to the water utilities. Many water supply sector contractors carry ISO 9001 accreditation.

HACCP is compatible with and often implemented alongside existing ISO standards such as the 9000 series (quality management), ISO 14000 series (environmental management), and 18000 series (occupational health and safety management) to form a comprehensive framework that can be used to analyze, prevent, and manage risks (EPA, 2007).

2.4.2 Risk Management Systems

The benefit for systematic control is widely accepted, and QA systems are now well developed and being implemented in water systems; however, it is possible to implement and gain accreditation for a QA system for water systems without adequately considering risks to safety. Risk assessment is not necessarily undertaken as part of QA system implementation.

Risk management systems, at their simplest, provide checklists of things to consider. At their most complex, they involve extensive administrative and engineered controls and checks and balances to ensure that everything has been considered and is under control. The level of complexity is related to the level of risk of the activity and the level of funding available. At one extreme, a small rural rainwater tank supply may need no more than very simple guidance notes and a brief checklist. At the other extreme, a nuclear power station needs multiple levels of administrative and automated systems to reduce the risk of an incident to less than negligible. Most water supplies fall somewhere in between. The levels of funding and risk are both relatively low in most circumstances.

There are a wide variety of systematic approaches for assessing and managing risks that can be integrated as part of a QA system or applied independently of it. Such systems include:

- Risk Management Standard ISO 31000:2009 (ISO, 2009)
- Failure modes effects analysis; Failure modes effects and criticality analysis (FMECA)
- Hazard and operability (HAZOP) and process hazard analysis (PHA); HACCP

The Risk Management Standard is a generally applicable standard that can be applied to the consideration of any risk and includes loops to consider risk management. HACCP is more specifically designed to consider risks to the safety and consumer acceptability of a consumed product. FMECA, HAZOP, and PHA are engineering and operational risk assessment and management tools. All of these tools are widely applied in the engineering profession, including the water sector. HACCP is consistent with these tools and often applied alongside them.

2.4.3 Other Quality and Risk Management Systems Applied Within the Sector

The application of quality and risk management systems in the water sector could be considered to go back to antiquity through the application of rules of thumb and traditional practices. Modern Western civilization began to systematize water supply practices in the 19th century to the point where design specifications and SOP ensured the provision of safe water.

Modern water supply systems make widespread use of automated monitoring and alert systems to manage drinking water supply. HACCP places considerable reliance on the early detection of deviations, making the use of automated monitoring and alert systems critical to practicable HACCP application. Thus, modern monitoring and control technologies have provided the opportunity to apply HACCP to the water sector.

During the past decade, there has been a rapid international implementation of risk management systems in the water sector (e.g., Havelaar, 1994; Deere and Davison, 1998; Cotruvo, 2004). The systems are used to optimize the use of the reliable engineering systems and operating practices that have become accepted practices over the previous century. Although these risk management systems make use of the state of the art in monitoring techniques, their successful application is as much about managing people as managing the physical assets.

Every entity that is accountable for an aspect of water management may choose particular systems based on previous experience within other industries or parts of the world. Others may choose systems that fit tightly within their existing organizational risk management systems. In any case, there is a substantial range of systems to choose from. Notwithstanding the value of some autonomy and using the most appropriate approach for themselves, there are some advantages in adopting some type of standard approach to water quality risk management. These include:

- pooling resources and progressing more efficiently when the industry is heading in a common direction
- using a common point of reference facilitates discussion, comparison, benchmarking and collaboration between different parties
- using common management systems, with cross-industry familiarity, which enables more seamless transfer of expertise between utilities and countries and roles (regulator, researcher, operator)

2.5 Challenge in Applying HACCP in the Water Sector

One challenging aspect of the application of HACCP to industries other than the food industry is that the HACCP system has developed an associated set of concepts and terminology that may be new to people and not always intuitively meaningful. For example, what is the difference between validation and verification? What is a CCP? Additional confusion may arise where several terms are in common use that are intended to mean the same thing, even within the food sector. For example, how are PRPs different from supporting programs, or are they in fact synonymous? Finally, a negative reaction may occur when attempting to apply HACCP to water among some professionals who are put off by the common use of words that are clearly specific to the production of food. Most HACCP training courses and texts talk about identifying food safety hazards or the vital importance of adopting good manufacturing practice, which have a clear definition in food but are not familiar phrases in the water sector.

For WHO, this food sector connotation led to the use of the WSP in preference to HACCP. Because HACCP is a food sector term and necessarily implies an international standard of product safety, it was considered by those working on the WSP document for WHO that the term WSP would be better suited to the water sector (Deere, personal communication, 2010). The food sector connotations of HACCP were considered to be likely to lead to rejection by water sector professionals because water has not traditionally been aligned closely with the food sector.

Many water supplies in the developing world would not meet an international standard of food safety at the tap. Therefore, it was considered that having HACCP as the target would lead to rejection—it would be considered too hard to achieve.

The WSP provides a framework for managing the current water supply assets to meet locally defined, health-based targets. The WSP allows for incremental improvements over many years, acknowledging that the water might not be considered safe or of a food grade in an international context for perhaps many decades, until major investments had been implemented. In that sense, the WSP is more of an improvement planning tool. HACCP is also an improvement planning tool, but it is usually applied in the context of certification according to a third party–audited pass/fail standard. The HACCP pass mark requires a relatively high, internationally acceptable, safe food grade to pass, not something that many low income regions can achieve now or for some decades to come.

Approximately 20 years ago, given the state of automation and formalization in the water industry, Bryan (1993) cautioned that the use of HACCP for the water industry was limited for a number of reasons:

- The structure, equipment, and cleaning standards applied in the water industry may be inappropriate (it is not typically of a food production facility standard).
- Effective communication may be lacking, preventing swift action when a problem occurs. (Many of the processes typically do not take place in an enclosed, controlled factory setting, and smaller utilities tend to lack reliable supervisory control and data acquisition [SCADA] systems to detect and divert water that is out of specifications. This comment was made in 1993, and this issue is becoming less significant as the water industry modernizes.)
- The appropriate corrective actions may not be clearly documented. (The sector is typically quite informal and has relatively few documented procedures. Once again, since 1993 that has been changing and continues to change.)
- The causative agent of waterborne disease outbreaks cannot always be isolated from either the water supply or the human case because of the lack of analytical methods for many pathogenic viruses and other microorganisms associated with drinking water samples. (The same could be said for food and bottled water, where HACCP is applied. Most existing analytical methods do not utilize online technologies, preventing an instantaneous reaction to failure. This can be addressed by monitoring

physical parameters to control critical points [e.g., monitor particle counts to assess the possible presence of *Cryptosporidium* oocysts].).

- If HACCP is applied only to treatment facilities and not the distribution system, it may not prevent a waterborne disease outbreak caused by distribution system inadequacies. (HACCP could of course be applied to distribution systems [e.g., Martel et al., 2006].)

Since 1993, many of the limitations identified by Bryan (1993) have been resolved, and for many large potable and recycled water schemes the issues effectively no longer apply.

Havelaar (1994) noted that a key issue in applying HACCP to water supply is properly identifying the CCPs (i.e., those points within the system or its operation the disruption or failure of which would result in a greater public health risk compared to other points). The major efforts in process control will be directed towards these CCPs. In many food operations, the heating step or another single step is the major barrier to pathogens. In water systems, multiple steps should be considered as CCPs because a multiple barrier approach is used to control microorganisms (e.g., source protection, filtration, and disinfection).

The major adaptation in applying HACCP to the water sector as distinct from a typical food process is the continuity of the essential supply to consumers. Unlike an idealized manufacturing process, the provision of water often needs to be continuous, and the supply cannot always be batched, tested, and shut down for any extended period of time if problems are detected. Furthermore, shutting down a water supply is rarely an option because water supply needs to be maintained for firefighting, sanitation, and other general uses. This makes the monitoring and corrective action procedures more difficult to apply, particularly where there is no alternative water source available. In practice, the same is often true, or partly true, for food, however, and sometimes recalls need to be issued after food has been supplied to the market. Furthermore, the boil water advisory (or equivalent) is similar to a product recall or advisory to avoid consumption of certain foods.

Acceptance, rather than technical, barriers to the use of HACCP in the water sector include the HACCP jargon, which can cause confusion when new, and the strong associations between HACCP and the food sector. For instance, the term CCP was not preferred by WHO and New Zealand Ministry of Health, which have not made much use of the term in their WSP and PHRMP guidance, respectively; however, within Australia, the term was retained in the drinking water and recycled water guidelines.

2.6 Conclusions

HACCP can be usefully applied to urban water systems for potable water supply and water reclamation, recycling, and reuse. It is most readily applicable to treatment processes and less easily applied to source control, distribution system management, and point of use or user control.

HACCP is typically applied as one part of a broader management framework. Using HACCP efficiently and effectively for the control of microbial hazards in U.S. water reuse schemes would require its integration into existing management frameworks. It would be used to fill any gaps in or strengthen those frameworks.

Because water reuse is regulated by the states, it is probable that a state-by-state assessment would be warranted, building from a national guidance document. Chapter 3 examines the regulatory context of HACCP in the United States in more detail. This project will assist with national guidance and provide tools to help states and utilities implement HACCP for their reuse schemes to add value to their existing microbial control processes.

Chapter 3

International Literature Review—Part B

3.1 Overview of Recycled Water Regulations in the United States

This chapter provides a summary of the major recycled water regulations, including EPA Guidelines for Water Reuse and individual state water reclamation standards.

3.1.1 EPA Guidelines

EPA has established Guidelines for Water Reuse (2004) for the benefit of utilities and regulatory agencies, particularly in the United States. The guidelines cover water reclamation for nonpotable urban, industrial, and agricultural reuse as well as augmentation of potable water supplies through indirect reuse.

3.1.2 Individual State Standards

Twenty-five states have regulations regarding water reuse. In states where standards do not exist, the EPA guidelines can assist in developing reuse programs and appropriate regulations. Table 3.1 provides a list of each state's guidelines or regulations pertaining to water reuse.

Table 3.1. Summary of State Guidelines or Regulations for Water Reuse

State	Type	Agency	Rules
Alabama	guidelines	Department of Environmental Management	Guidelines and Minimum Requirements for Municipal, Semi-Public, and Private Land Treatment Facilities
Alaska	regulations	Department of Environmental Conservation	Alaska Administrative Code, Title 18—Environmental Conservation, Chapter 72, Article 2, Section 275—Disposal Systems
Arizona	regulations	Department of Environmental Quality	Arizona Administrative Code, Title 18—Environmental Quality, Chapter 11, Article 3—Reclaimed Water Quality Standards and Chapter 9, Article 7—Direct Reuse of Reclaimed Water
Arkansas	guidelines	Department of Environmental Quality	Arkansas Land Application Guidelines for Domestic Wastewater

Table 3.1. Summary of State Guidelines or Regulations for Water Reuse (*continued)*

State	Type	Agency	Rules
California	regulations	CDPH	CCR, Title 17 and Title 22, CDPH—Regulations and Guidance for Recycled Water ("The Purple Book") and Draft Groundwater Recharge Reuse Regulations
Colorado	regulations	Department of Public Health and Environment	Water Quality Control Commission Regulation 84—Reclaimed Domestic Wastewater Control Regulation
Connecticut	neither	Department of Environmental Protection	
Delaware	regulations	Department of Natural Resources and Environmental Control	Guidance and Regulations Governing the Land Treatment of Wastes
Florida	regulations	Department of Environmental Protection	Reuse of Reclaimed Water and Land Application Florida Administrative Code—Chapter 62-610
Georgia	guidelines	Department of Natural Resources	Environmental Protection Division Guidelines for Water Reclamation and Urban Water Reuse
Hawaii	guidelines	Department of Health	Guidelines for the Treatment and Use of Recycled Water
Idaho	regulations	Department of Environmental Quality	58.01.17 Wastewater Land Application Permit Rules
Illinois	regulations	Environmental Protection Agency	Illinois Administrative Code, Title 35, Subtitle C, Part 372, Illinois Design Standards for Slow Rate Land Application of Treated Wastewater
Indiana	regulations	Department of Environmental Management	Indiana Administrative Code, Title 327, Article 6.1—Land Application of Biosolids, Industrial Waste Product, and Pollutant-Bearing Water
Iowa	regulations	Department of Natural Resources	Environmental Protection Division, Iowa Wastewater Design Standards, Chapter 21—Land Application of Wastewater

Table 3.1. Summary of State Guidelines or Regulations for Water Reuse *(continued)*

State	Type	Agency	Rules
Kansas	guidelines	Department of Health and Environment	Department of Health and Environment Administrative Rules and Regulations, 28-16. Water Pollution Control
Kentucky	neither		
Louisiana	neither		
Maine	neither		
Maryland	guidelines	Department of the Environment	Guidelines for Land Treatment for Municipal Wastewaters, Title 26, Department of the Environment
Massachusetts	guidelines	Massachusetts Department of Environmental Protection	Interim Guidelines on Reclaimed Water (revised)
Michigan	regulations	Department of Environmental Quality	Part 22, Rules of Part 31, Groundwater Quality Rules; Part 22, Guidesheet II, Irrigation Management Plan Rule 2215, Various Aboveground Disposal Systems
Minnesota	neither		
Mississippi	neither		
Missouri	regulations	Department of Natural Resources	Code of State Regulations, Title 10, Division 20, Chapter 8—Design Guides
Montana	guidelines	Department of Environmental Quality	Design Standards for Wastewater Facilities, Appendix B, Standards for the Spray Irrigation of Wastewater
Nebraska	regulations	Department of Environmental Quality	Title 119, Chapter 9, Disposal of Sewage Sludge and Land Application of Effluent; refers to the use of Guidelines for Treated Wastewater Irrigation Systems, February 1986
Nevada	regulations	Department of Conservation and Natural Resources	Division of Environmental Protection, Nevada Administrative Code 445A.275—Use of Treated Effluent for Irrigation General Design Criteria for Reclaimed Water Irrigation Use
New Hampshire	neither		

Table 3.1. Summary of State Guidelines or Regulations for Water Reuse *(continued)*

State	Type	Agency	Rules
New Jersey	guidelines	Department of Environmental Protection, Division of Water Quality	Technical Manual for Reclaimed Water for Beneficial Reuse
New Mexico	guidelines	Environment Department	Use of Domestic Wastewater Effluent for Irrigation
New York	guidelines	Department of Environmental Conservation	State Guidelines for the Use of Land Treatment of Wastewater
North Carolina	regulations	Department of Environment and Natural Resources	Administrative Rules, Title 15A, Chapter 02, Subchapter 2H, Section .0200—Waste Not Discharged to Surface Waters
North Dakota	guidelines	Department of Health	Division of Water Quality Criteria for Irrigation with Treated Wastewater Recommended Criteria for Land Disposal of Effluent
Ohio	guidelines	Environmental Protection Agency	The Ohio State University Extension Bulletin 860, Reuse of Reclaimed Wastewater Through Irrigation
Oklahoma	regulations	Department of Environmental Quality	Title 252, Chapters 621 and 656
Oregon	regulations	Department of Environmental Quality	Oregon Administrative Rules, Use of Reclaimed Water from Sewage Treatment Plants—Division 55 340-055, Treatment and Monitoring Requirements for Use of Reclaimed Water
Pennsylvania	guidelines	Department of Environmental Protection	Bureau of Water Quality Protection Manual for Land Application of Treated Sewage and Industrial Wastewater
Rhode Island	neither		
South Carolina	regulations	Department of Health and Environmental Control	Administrative Code 61, Section 9.505, Land Application Permits and State Permits

Table 3.1. Summary of State Guidelines or Regulations for Water Reuse *(continued)*

State	Type	Agency	Rules
South Dakota	guidelines	Department of Environment and Natural Resources	Chapter XII, Recommended Design Criteria for Disposal of Effluent by Irrigation, Chapter XIII, Recommended Design Criteria for Groundwater Monitoring Wells, Chapter XVI, Recommended Design Criteria for Artificial Wetland Systems
Tennessee	regulations	Department of Environment and Conservation	Chapter 16 of Design Criteria for Sewage Works
Texas	regulations	Natural Resource Conservation Commission	Texas Administrative Code, Title 30, Environmental Quality, Part 1, Chapter 210, Use of Reclaimed Water
Utah	regulations	Department of Environmental Quality, Division of Water Quality, Agency of Natural Resources	Utah Administrative Code, Environmental Quality, R-317-1-4
Vermont	regulations	Department of Environmental Conservation	Indirect Discharge Rules (for systems >6500 gpd), Wastewater Disposal Systems and Potable Water Supplies (for systems <6500gpd)
Virginia	neither	Department of Environmental Quality	
Washington	guidelines	Department of Health, State	Department of Ecology Water Reclamation and Reuse Standards
West Virginia	regulations	Department of Health	Title 64, Series 47, Chapter 16-1, Sewage Treatment and Collection System Design Standards
Wisconsin	regulations	Department of Natural Resources	Natural Resources, Chapter NR 206, Land Disposal of Municipal and Domestic Wastewaters
Wyoming	regulations	Department of Environmental Quality	Wyoming Water Quality Regulations, Chapter 21—Reuse of Treated Wastewater

Notes: CCR=California Code of Regulations; CDPH=California Department of Public Health

Arizona, California, Colorado, Florida, Hawaii, Nevada, New Jersey, Oregon, Texas, Utah, and Washington have extensive regulations or guidelines that prescribe requirements for a wide range of recycled water uses. California and Florida compile comprehensive inventories of reuse projects by type of reuse application.

Many of the water reclamation guidelines and regulations in the United States have HACCP-like elements. Depending on the end use of the recycled water, the risks are identified, analyzed, and evaluated. To minimize risks, optimum treatment and reliability provisions are established in the standards along with required monitoring programs and reporting of the recycled water quality. Records of the reclamation system management and operator certifications are also required by the majority of the guidelines and regulations.

3.2 Comparison of California Water Recycling Requirements with HACCP Approach

The water recycling criteria in California are compared with the HACCP approach in this section as an example of U.S. water reclamation practices. Following an overview of the regulations, the provisions are compared with the HACCP steps and principles.

- California Code of Regulations (CCR) Titles 22 and 17
- Other CDPH water reclamation guidelines and criteria
- Comparison with HACCP approach

3.2.1 Title 22 Water Recycling Criteria Overview

The CDPH establishes criteria and guidelines for producing and using recycled water. These criteria are codified in CCR Title 22, Division 4, Chapter 3, entitled Water Recycling Criteria (California, 2001). Commonly referred to as Title 22 criteria, the treatment and effluent quality requirements are dependent on the proposed type of reuse. In addition to these requirements, Title 22 specifies reliability criteria to ensure protection of public health. The State Water Resources Control Board and its nine Regional Water Quality Control Boards (RWQCB) are responsible for enforcing these criteria.

3.2.1.1 Treatment, Water Quality Reliability

In general, Title 22 requires that wastewater be treated using designated processes to achieve a specified level of quality. Higher quality effluents, such as disinfected tertiary recycled water or disinfected advance-treated recycled water, may be utilized for more types of reuse with fewer restrictions. Lower quality effluents, such as disinfected secondary effluent or nondisinfected secondary effluent, have restricted uses. Two of the main factors determining use restrictions are the degree to which the public has exposure or access to areas where recycled water is used and the proximity of drinking water wells and food crops.

Title 22 requires that wastewater be oxidized, which means that its organic matter has been stabilized, is nonputrescible, and contains dissolved oxygen. Secondary treatment is necessary to produce oxidized and stabilized wastewater.

Moving beyond secondary treatment is tertiary treatment, which involves coagulation and media filtration or membrane filtration to meet Title 22 turbidity criteria measured in nephelometric turbidity units (NTU) for many types of reuse.

Title 22 (Section 60301.320) defines filtered wastewater as

> an oxidized wastewater that meets the criteria in subsection (a) or (b):
>
> (a) Has been coagulated and passed through natural undisturbed soils or a bed of filter media pursuant to the following:
>
> (1) At a rate that does not exceed 5 gallons per minute per square foot of surface area in mono, dual, or mixed media gravity, upflow, or pressure filtration systems, or does not exceed 2 gallons per minute per square foot of surface area in traveling bridge automatic backwash filters [a rate that does not exceed 6 gallons per minute per square foot of surface area for cloth disc filters has been approved]; and
>
> (2) So that the turbidity of the filtered wastewater does not exceed any of the following:
>
> (A) An average of 2 NTU within a 24-hour period;
>
> (B) 5 NTU more than 5 percent of the time within a 24-hour period; and
>
> (C) 10 NTU at any time.
>
> (b) Has been passed through a microfiltration, ultrafiltration, nanofiltration, or reverse osmosis membrane so that the turbidity of the filtered wastewater does not exceed any of the following:
>
> (1) 0.2 NTU more than 5 percent of the time within a 24-hour period; and
>
> (2) 0.5 NTU at any time.

Following tertiary treatment, disinfection ensures that the recycled water is safe for reuse with unrestricted public contact.

According to Title 22 (Section 60301.230),

> disinfected, tertiary recycled water means a filtered and subsequently disinfected wastewater that meets the following criteria:
>
> (a) The filtered wastewater has been disinfected by either:
>
> (1) A chlorine disinfection process following filtration that provides a CT (the product of total chlorine residual and modal contact time measured at the same point) value of not less than 450 milligram-minutes per liter at all times with a modal contact time of at least 90 minutes, based on peak dry weather design flow; or
>
> (2) A disinfection process that, when combined with the filtration process, has been demonstrated to inactivate and/or remove 99.999 percent of the plaque-forming units of F-specific bacteriophage MS2, or polio virus in the wastewater. A virus that is at least as resistant to disinfection as polio virus may be used for purposes of the demonstration.
>
> (b) The median concentration of total coliform bacteria measured in the disinfected effluent does not exceed an MPN [most probable number] of 2.2 per 100 milliliters utilizing the bacteriological results of the last seven days for which analyses have been completed and the number of total coliform bacteria does not exceed an MPN of 23 per 100 milliliters in more than one sample in any 30 day period. No sample shall exceed an MPN of 240 total coliform bacteria per 100 milliliters.

Where ultraviolet light (UV) is used for disinfection, the UV system must comply with the Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse published by the National Water Research Institute (NWRI; 2012). For recycled water, these guidelines specify minimum UV dose criteria for different upstream filtration technologies (media filtration, membrane filtration, and RO). The UV system must deliver, under worst operating conditions, a designated minimum UV dose at the maximum weekly and peak daily flow, as approved by CDPH for specific manufacturers and models of UV equipment.

Title 22 (Section 60320.5) specifies that other methods of treatment and their associated reliability features may be acceptable to CDPH if they are demonstrated as equivalent to the treatment methods and reliability features set forth in Title 22.

In addition to treatment and quality requirements, Title 22 contains reliability requirements and provisions for alarms to be included in the design of facilities. Title 22 (Articles 9 and 10) specifies that the facilities must be designed to provide operational flexibility. Multiple treatment units capable of producing the required quality must be provided in the event that one unit is not in operation. In place of multiple units, alternative treatment processes, storage, or disposal provisions may be included for redundancy. Alarms are required to alert plant operators of failure of the power supply or any treatment plant unit processes. Title 22 also requires the plant to set up either a standby power source or automatically actuated short- or long-term storage or disposal provisions in the event of a power supply failure.

Recycled water quality sampling and analyses requirements are set forth in Title 22, Article 6, to monitor treatment performance for compliance with total coliform bacteria limits and turbidity. The regulations also include requirements for operations personnel (Section 60325), maintenance (Section 60326), and reporting (Section 60329). Bypassing treatment processes or discharge of inadequately treated effluent are not allowed (Section 60331).

In order to assure that recycled water facilities comply with the regulations, Title 22 (Section 60323) requires submittal of an engineering report describing the proposed recycled water system and the means for system compliance with listed requirements to the RWQCB and CDPH for approval. The engineering report must be amended or resubmitted in the event that there are significant modifications to an existing project.

3.2.1.2 Use of Recycled Water

Title 22, Article 3, provides for many types of recycled water use. Table 3.2 summarizes the currently approved recycled water uses.

Table 3.2. Summary of Existing Allowable Recycled Water Uses

Allowable Title 22 Recycled Water Uses	Title 22 Section
Irrigation	
Food crops for which recycled water contacts the edible portion of the crop, including all root crops	60304 (a) (1)
Parks and playgrounds	60304 (a) (2)
School yards	60304 (a) (3)
Residential landscaping	60304 (a) (4)
Unrestricted-access golf courses	60304 (a) (5)
Any other irrigation uses not prohibited by other provisions of the CCR	60304 (a) (6)
Food crops, surface-irrigated, above-ground edible portion not contacted by recycled water	60304 (b)
Cemeteries	60304 (c) (1)
Freeway landscaping	60304 (c) (2)
Restricted-access golf course	60304 (c) (3)
Ornamental nursery stock and sod farms with unrestricted public access	60304 (c) (4)
Pasture for milk animals for human consumption	60304 (c) (5)
Nonedible vegetation with access control to prevent use as park, playground, or school yard	60304 (c) (6)
Orchards with no contact between edible portion and recycled water	60304 (d) (1)
Vineyards with no contact between edible portion and recycled water	60304 (d) (2)
Nonfood-bearing trees, including Christmas trees not irrigated less than 14 days before harvest	60304 (d) (3)
Fodder and fiber crops and pasture for animals not producing milk for human consumption	60304 (d) (4)
Seed crops not eaten by humans	60304 (d) (5)
Food crops undergoing commercial pathogen-destroying processing before consumption by humans	60304 (d) (6)
Ornamental nursery stock and sod farms not irrigated less than 14 days before harvest, sale, or allowing public access	60304 (d) (7)
Supply for impoundment	
Unrestricted recreational impoundments, with disinfected tertiary recycled water that has received conventional treatment	60305 (a)
Unrestricted recreational impoundments, with disinfected tertiary recycled water with supplemental monitoring for pathogenic organisms in place of conventional treatment	60305 (b)
Restricted recreational impoundments and publicly accessible fish hatcheries	60305 (d)
Landscape impoundments without decorative fountains	60305 (e)

Table 3.2. Summary of Existing Allowable Recycled Water Uses (*continued*)

Allowable Title 22 Recycled Water Uses	Title 22 Section
Supply for Cooling and Air Conditioning	
Industrial or commercial cooling or air conditioning involving cooling tower, evaporative condenser, or spraying that creates a mist	60306 (a)
Industrial or commercial cooling or air conditioning not involving cooling tower, evaporative condenser, or spraying that creates a mist	60306 (b)
Other Uses	
Dual plumbing systems (flushing toilets and urinals)	60307 (a) (1)
Priming drain traps	60307 (a) (2)
Industrial process water that may contact workers	60307 (a) (3)
Structural firefighting	60307 (a) (4)
Decorative fountains	60307 (a) (5)
Commercial laundries	60307 (a) (6)
Consolidation of backfill material around potable water pipelines	60307 (a) (7)
Artificial snowmaking for commercial outdoor uses	60307 (a) (8)
Commercial car washes, not heating the water, excluding the general public from washing process	60307 (a) (9)
Industrial boiler feed	60307 (b) (1)
Nonstructural firefighting	60307 (b) (2)
Backfill consolidation around nonpotable piping	60307 (b) (3)
Soil compaction	60307 (b) (4)
Mixing concrete	60307 (b) (5)
Dust control on roads and streets	60307 (b) (6)
Cleaning roads, sidewalks, and outdoor work areas	60307 (b) (7)
Industrial process water that will not come into contact with workers	60307 (b) (8)
Flushing sanitary sewer	60307 (c)
Groundwater recharge	60320 (a)

Note: CCR=California Code of Regulations

As noted in this table, irrigation with recycled water is a common application. Depending on the level of treatment and quality, recycled water may be used to irrigate numerous different areas (Section 60304). For example, disinfected tertiary recycled water may be used to irrigate parks and school yards, whereas disinfected secondary effluent may be used to irrigate cemeteries and freeway landscaping, and nondisinfected secondary effluent may be used to irrigate non-food-bearing trees and orchards where the recycled water does not come into contact with the edible crop. Disinfected tertiary water may be used in place of the lower quality recycled waters for irrigation.

Disinfected tertiary effluent may be used for unrestricted recreational impoundments (Section 60305). Disinfected secondary or tertiary effluent may be used for restricted recreational impoundments and publicly accessible impoundments at fish hatcheries.

Specifically, Title 22 (Section 60301.620) defines an unrestricted recreational impoundment as "an impoundment of recycled water, in which no limitations are imposed on body-contact water recreational activities." With regard to use of recycled water for impoundments, Title 22 (Section 60305) states:

> (a) Except as provided in subsection (b), recycled water used as a source of water supply for non-restricted recreational impoundments shall be disinfected tertiary recycled water that has been subjected to conventional treatment.
>
> (b) Disinfected tertiary recycled water that has not received conventional treatment may be used for non-restricted recreational impoundments provided the recycled water is monitored for the presence of pathogenic organisms in accordance with the following:
>
> (1) During the first 12 months of operation and use the recycled water shall be sampled and analyzed monthly for Giardia, enteric viruses, and Cryptosporidium. Following the first 12 months of use, the recycled water shall be sampled and analyzed quarterly for Giardia, enteric viruses, and Cryptosporidium. The ongoing monitoring may be discontinued after the first two years of operation with the approval of the [CDPH]. This monitoring shall be in addition to the monitoring set forth in Section 60321.
>
> (2) The samples shall be taken at a point following disinfection and prior to the point where the recycled water enters the use impoundment. The samples shall be analyzed by an approved laboratory and the results submitted quarterly to the regulatory agency.
>
> (c) The total coliform bacteria concentrations in recycled water used for non-restricted recreational impoundments, measured at a point between the disinfection process and the point of entry to the use impoundment, shall comply with the criteria specified in Section 60301.230 (b) for disinfected tertiary recycled water.
>
> (d) Recycled water used as a source of supply for landscape impoundments that do not utilize decorative fountains shall be at least disinfected secondary-23 recycled water.

Title 22 (Section 60306) allows disinfected tertiary recycled water to be used for cooling purposes where mist may be created. If the application does not produce mist, then at least disinfected secondary effluent must be used. Title 22 (Section 60307) includes provisions for many other types of reuse, as listed in Table 3.2. Disinfected tertiary effluent may be used for any of these uses.

Title 22 (Section 60320) covers recycled water use for groundwater recharge of domestic water supply aquifers. It specifies that CDPH make recommendations to the RWQCB for groundwater recharge projects on a case-by-case basis. CDPH has published Draft Groundwater Recharge Criteria for indirect potable reuse.

3.2.2 Title 17 Backflow Prevention Overview

Title 17, Division 1, Chapter 5, Sanitation (Environmental), Group 4, Drinking Water Supplies, of the CCR (California, 2009) specifies that the water supplier must protect the public drinking water supply from contamination by implementation of a cross-connection control program. Title 17 (Group 4, Article 2) sets forth requirements for protection of the water system and specifies the minimum backflow prevention required on the potable water system for situations where there is potential for contamination to the potable water supply. For recycled water, construction and location of backflow preventers is addressed in Title 17 as follows:

- An air-gap separation shall be at least double the diameter of the supply pipe, measured vertically from the flood rim of the receiving vessel to the supply pipe. The air-gap separation shall be located as close as practical to the user's connection, and all piping between the user's connection and the receiving tank shall be entirely visible unless otherwise approved in writing by the local health agency (typically city, county, or both).
- A double check valve assembly shall conform to American Water Works Association (AWWA) standards, be located as close as practical to the user's connection, and be installed above grade, if possible, in a manner that it is readily accessible for testing and maintenance.
- A reduced pressure principle backflow prevention device shall conform to AWWA standards and be located as close as practical to the user's connection and installed a minimum of 12 inches above grade, not more than 36 inches above grade from the bottom of the device, with a minimum of 12 inches side clearance.

An air-gap separation is defined as a physical break between the supply line and a receiving vessel. A double check valve assembly has at least two independently acting check valves including tightly closing shut-off valves on each side of the check valve assembly and test cocks available for testing the water tightness of each check valve. A reduced pressure principle backflow preventer is a backflow prevention device incorporating at least two check valves, an automatically operated differential relief valve located between the two check valves, a tightly closing shut-off valve on each side of the check valve assembly, and necessary test cocks.

3.2.3 Other CDPH Guidance Criteria

In addition to the Titles 22 and 17 regulations previously described, CDPH has other documents related to recycled water production and use:

- Guidelines for the Preparation of an Engineering Report for the Production, Distribution, and Use of Recycled Water (CDPH, 2001). This report provides a framework to assist in developing a Title 22 Engineering Report that addresses the necessary elements of a proposed or modified recycled water project to facilitate regulatory review and approval.
- Treatment Technology Report for Recycled Water (CDPH, 2007). This report provides reference information about treatment technologies meeting filtration performance and disinfection requirements for compliance with Title 22.
- Guidance Memo No. 2003-02: Guidance Criteria for the Separation of Water Mains and NonPotable Pipelines (CDPH, 2003). This memorandum provides separation

criteria for design and installation of drinking water and nonpotable (recycled water and sewers) pipelines to prevent contamination of the drinking water supply.

- Draft Groundwater Recharge Reuse Criteria (CDPH, 2008). These draft criteria reflect CDPH's views on the regulation of recharge of groundwater with recycled municipal wastewater. An update to these draft criteria was provided in 2011, but the formal regulations are not scheduled to be proposed until 2014.

3.2.4 Comparison of California Requirements with HACCP Approach

As noted earlier, the HACCP approach is used in the food industry in the United States, but it has not been applied to the water industry. Table 3.3 presents a matrix comparing the key elements of the 12 HACCP steps with Titles 22 and 17 provisions. Some California water recycling criteria closely parallel the requirements of the HACCP system. Others partially match the HACCP approach but miss some components. Many HACCP plan elements are simply not included in the California regulations.

Table 3.3. General Comparison of HACCP Approach and California Title 22 Requirements

HACCP Step and Key Criteria	California Code of Regulations – Title 22 – Key Elements of Water Recycling Criteria						
	Plant Performance Monitoring					RW Use Areas	
	Filter Influent Turbidity	Continuous Turbidity Monitoring	Filter Effluent Turbidity	Effluent Total Coliform	Disinfection Process Monitoring	RW Use Area Require-ments	Cross-Connection Control
	T22, Div. 4, Ch. 3, Art. 3, 60304	T22, Div. 4, Ch. 3, Art. 3, 60304; Art. 6, 60321	T22, Div. 4, Ch. 3, Art. 3, 60304	T22, Div. 4, Ch. 3, Art. 3, 60304; Art. 6, 60321	T22, Div. 4, Ch. 3, Art. 3, 60304; Art. 6, 60353	T22, Div. 4, Ch. 3, Art. 3, 60304; Art. 6, 60310	T17, Div. 1, Ch. 5, Group 4
1. Assemble a HACCP Team							
Commitment from senior management							
Quality assurance							⊖
Roles and responsibilities						●	●
Internal communication							
2. Describe the Product							
Source control and raw waste-water quality							
Recycled water production specification	●	●	●		●	●	
3. Identify Intended Use							
Regulatory awareness						●	●
External communication						●	●
Standards	●		●	●	●		
4. Identify Intended Use							
Process flow diagram							
Traceability						●	●
5. Identify Intended Use							
Process validation			●	●	●		
6. Conduct Hazard Analysis							
Hazard analysis							
7. Identify Critical Control Points							
Critical control points							

Table 3.3. General Comparison of HACCP Approach and California Title 22 Requirements

HACCP Step and Key Criteria	California Code of Regulations – Title 22 – Key Elements of Water Recycling Criteria						
	Plant Performance Monitoring					RW Use Areas	
	Filter Influent Turbidity	Continuous Turbidity Monitoring	Filter Effluent Turbidity	Effluent Total Coliform	Disinfection Process Monitoring	RW Use Area Require-ments	Cross-Connection Control
	T22, Div. 4, Ch. 3, Art. 3, 60304	T22, Div. 4, Ch. 3, Art. 3, 60304; Art. 6, 60321	T22, Div. 4, Ch. 3, Art. 3, 60304	T22, Div. 4, Ch. 3, Art. 3, 60304; Art. 6, 60321	T22, Div. 4, Ch. 3, Art. 3, 60304; Art. 6, 60353	T22, Div. 4, Ch. 3, Art. 3, 60304; Art. 6, 60310	T17, Div. 1, Ch. 5, Group 4
8. Establish Critical Limits							
Critical limits							
Preventive measures							
9. Identify Monitoring Procedures							
Monitoring and control		⊖	⊖		⊖		
Verification – process (end point)						⊖	⊖
External supplies							
10. Establish Corrective Action Procedures							
Emergency preparedness							
Corrective action		⊖	⊖		⊖		
Non-complying product							
Maintenance							
Training						●	●
Calibration							
11. Validate/Verify HACCP Plan							
Verification – internal audit							
Management review							
Product performance							
Feedback loops							⊖
Continuous improvement							
Contractors							

Table 3.3. General Comparison of HACCP Approach and California Title 22 Requirements

HACCP Step and Key Criteria	California Code of Regulations – Title 22 – Key Elements of Water Recycling Criteria						
	Plant Performance Monitoring					RW Use Areas	
	Filter Influent Turbidity	Continuous Turbidity Monitoring	Filter Effluent Turbidity	Effluent Total Coliform	Disinfection Process Monitoring	RW Use Area Require-ments	Cross-Connection Control
	T22, Div. 4, Ch. 3, Art. 3, 60304	T22, Div. 4, Ch. 3, Art. 3, 60304; Art. 6, 60321	T22, Div. 4, Ch. 3, Art. 3, 60304	T22, Div. 4, Ch. 3, Art. 3, 60304; Art. 6, 60321	T22, Div. 4, Ch. 3, Art. 3, 60304; Art. 6, 60353	T22, Div. 4, Ch. 3, Art. 3, 60304; Art. 6, 60310	T17, Div. 1, Ch. 5, Group 4
12. Establish Documentation and Recordkeeping							
Document control							

Legend: Are Title 22 replacements equivalent to HACCP approach?	**Yes**	●	**Partial**	⊖	**No**	

(continued)

Table 3.3. General Comparison of HACCP Approach and California Title 22 Requirements

HACCP Step and Key Criteria	California Code of Regulations – Title 22 – Key Elements of Water Recycling Criteria							
	Plant Design					Plant Operation/Maintenance		
	Process Design Reliability	Standby Power	Unit Process Alarms	Process Design Flexibility	Engineer-ing Report	WW Operator Training	Operating Records/ Reporting	Preventive Mainten-ance
	T22, Div. 4, Ch. 3, Art. 9 & 10	T22, Div. 4, Ch. 3, Art. 8, 60337	T22, Div. 4, Ch. 3, Art. 8, 60335	T22, Div. 4, Ch. 3, Art. 8, 60333	T22, Div. 4, Ch. 3, Art. 7, 60323	T22, Div. 4, Ch. 3, Art. 7, 60325	T22, Div. 4, Ch. 3, Art. 7, 60329	T22, Div. 4, Ch. 3, Art. 7, 60327
1. Assemble a HACCP Team								
Commitment from senior management						⊖	⊖	⊖
Quality assurance						⊖		
Roles and responsibilities						●		
Internal communication						●		
2. Describe the Product								
Source control and raw waste-water quality			●				●	
Recycled water production specification			●				●	
3. Identify Intended Use								
Regulatory awareness					●	●		
External communication								
Standards								
4. Identify Intended Use								
Process flow diagram	●				●			
Traceability					●		●	
5. Identify Intended Use								
Process validation					●		●	
6. Conduct Hazard Analysis								
Hazard analysis								
7. Identify Critical Control Points								
Critical control points			⊖		⊖			

Table 3.3. General Comparison of HACCP Approach and California Title 22 Requirements

HACCP Step and Key Criteria	California Code of Regulations – Title 22 – Key Elements of Water Recycling Criteria							
	Plant Design					Plant Operation/Maintenance		
	Process Design Reliability	Standby Power	Unit Process Alarms	Process Design Flexibility	Engineer-ing Report	WW Operator Training	Operating Records/ Reporting	Preventive Mainten-ance
	T22, Div. 4, Ch. 3, Art. 9 & 10	T22, Div. 4, Ch. 3, Art. 8, 60337	T22, Div. 4, Ch. 3, Art. 8, 60335	T22, Div. 4, Ch. 3, Art. 8, 60333	T22, Div. 4, Ch. 3, Art. 7, 60323	T22, Div. 4, Ch. 3, Art. 7, 60325	T22, Div. 4, Ch. 3, Art. 7, 60329	T22, Div. 4, Ch. 3, Art. 7, 60327
8. Establish Critical Limits								
Critical limits			⊖		⊖			
Preventive measures								●
9. Identify Monitoring Procedures								
Monitoring and control			●				●	
Verification – process (end point)								
External supplies								
10. Establish Corrective Action Procedures								
Emergency preparedness	●	●	●					●
Corrective action			●				⊖	
Non-complying product	●			⊖				
Maintenance								●
Training						●		
Calibration							●	●
11. Validate/Verify HACCP Plan								
Verification – internal audit							⊖	
Management review						⊖		
Product performance						●	⊖	
Feedback loops							⊖	
Continuous improvement						●		
Contractors								

Table 3.3. General Comparison of HACCP Approach and California Title 22 Requirements

HACCP Step and Key Criteria	California Code of Regulations – Title 22 – Key Elements of Water Recycling Criteria							
	Plant Design					Plant Operation/Maintenance		
	Process Design Reliability	**Standby Power**	**Unit Process Alarms**	**Process Design Flexibility**	**Engineer-ing Report**	**WW Operator Training**	**Operating Records/ Reporting**	**Preventive Mainten-ance**
	T22, Div. 4, Ch. 3, Art. 9 & 10	T22, Div. 4, Ch. 3, Art. 8, 60337	T22, Div. 4, Ch. 3, Art. 8, 60335	T22, Div. 4, Ch. 3, Art. 8, 60333	T22, Div. 4, Ch. 3, Art. 7, 60323	T22, Div. 4, Ch. 3, Art. 7, 60325	T22, Div. 4, Ch. 3, Art. 7, 60329	T22, Div. 4, Ch. 3, Art. 7, 60327
12. Establish Documentation and Recordkeeping								
Document control					⊖		●	

Legend: Are Title 22 replacements equivalent to HACCP approach? **Yes** ● **Partial** ⊖ **No** (blank)

Chapter 4

Industry HACCP Data Analysis and Case Studies

4.1 Objectives

This chapter presents a synthesized review of documented HACCP plans from existing reclaimed water systems. In this review we have looked for the application of the HACCP steps and principles within documented recycled water management plans and provided examples and case studies based on the information reviewed. For the purposes of this chapter, the term HACCP plan will be used to refer to both explicit HACCP plans as well as to management plans that incorporate HACCP steps and principles. In some cases, the plans reviewed were explicitly termed HACCP plans, and in other cases, management plans were reviewed that explicitly incorporated the principles of HACCP but were called something else.

It should be noted that the application of HACCP as part of some broader framework is common practice. Confusion may arise when the HACCP steps and principles are applied within these broader frameworks, as in the following examples.

- Food sector: Food Safety Plans and plans with similar names are often broader than the most minimal application of HACCP.
- Drinking water sector: WSP or Drinking Water Quality Management Plans and plans with similar names are also often broader than the most minimal application of HACCP.
- Reuse sector: RWQMPs and plans with similar names are often broader than HACCP.

Participating utilities provided selected extracts from their HACCP plans, as permitted, given their security and confidentiality requirements. An in kind contribution of $5000 was estimated to allow each of these utilities to sort through and gain approval to release the relevant information and assign a nominal value to that information. The plans covered the broad range of reuse applications from low exposure irrigation schemes through urban dual reticulation or third-pipe schemes to potable reuse. A summary of the documents reviewed is given in Table 4.1.

The HACCP plans reviewed were summarized with respect to pertinent detailed aspects such as:

- high risks identified
- controls identified
- designation of CCP
- critical limit monitoring parameters and critical limit values
- validation evidence base
- verification requirements
- PRPs or sanitation SOP equivalents
- supporting programs identified

Table 4.1. HACCP Plans That Were Reviewed in Developing This Chapter

Utility Location of Scheme	Use(s) of water	Scale of Scheme	Risk and Quality Management System(s) in Place	Date System Externally Accredited or Certified	Source
PUB Singapore NEWater plants: Kranji Seletar Bedok	Industrial uses (e.g., silicon wafer fabrication plants for process, cooling and other nonpotable uses) Indirect potable use (surface water reservoir augmentation)	40 MGD 180 MLD	HACCP (SS 444:1998) ISO 9001:2008 ISO 14001:2004 OHSAS 18001:2007 WSP (Singapore regulations)	11/06 10/06 05/07 08/07	HACCP plans supplied by Harry Seah and Mark Wong from PUB Singapore in 2010
South East Water Boneo, Melbourne, Victoria, Australia	Unrestricted irrigation (e.g., for market gardens, golf courses, dust suppression, road works, firefighting practice, and watering of school and sports fields)	1.6 MGD 6 MLD	HACCP ISO 9001 ISO 14001 AS 4801 OHS RWQMP (Victoria regulations)	2009 for regulatory approval	HACCP plans supplied by David Smith from South East Water Australia in 2010
SA Water Glenelg-Adelaide Recycled Water Scheme, Adelaide, South Australia	Unrestricted irrigation (e.g., public open spaces, recreation grounds, sports grounds, golf courses)	9 MGD 35 MLD	Recycled Water (Supply) Mgmt Plan	2010 for regulatory approval	HACCP plans supplied by Grant Lewis South Australia Water Australia in 2010
Melbourne Water Werribee Irrigation District, Melbourne, Victoria, Australia	Unrestricted irrigation (e.g., food crops to be eaten raw, ornamental green spaces)	20 MGD 75 MLD	ISO 22000 (HACCP) ISO 14001 ISO 9001 RWQMP (Victoria regulations)	2005 for regulatory approval	HACCP plans supplied by Judy Blackbeard from Melbourne Water Australia in 2010
Yarra Valley Water Aurora, Melbourne, Victoria, Australia	Dual reticulation (e.g., urban, commercial, and industrial use, firefighting, and unrestricted public open space irrigation)	1 MGD 4 MLD	HACCP ISO 9001 ISO 14001 RWQMP (Victoria regulations)	2009 for regulatory approval	HACCP plans supplied by Asoka Jayaratne from Yarra Valley Water Australia in 2010

Table 4.1. HACCP Plans That Were Reviewed in Developing This Chapter *(continued)*

Utility Location of Scheme	Use(s) of water	Scale of Scheme	Risk and Quality Management System(s) in Place	Date System Externally Accredited or Certified	Source
Allconnex Water Gold Coast, Queensland, Australia	Restricted municipal use (e.g., dust suppression, compaction, controlled irrigation of turf, plants, and gardens, hydraulic testing, irrigation)	13 MGD 50 MLD	HACCP ISO 9001 ISO 14001 Recycled Water Mgmt Plan (Queensland regulations)	2010 for regulatory approval	HACCP plans supplied by Shannon McBride from Allconnex Australia in 2010
CWW Werribee Employment Precinct, Melbourne, Victoria, Australia	Dual reticulation (e.g., open space irrigation, toilet flushing, washdown of facilities and operation of sewer pump station)	0.3 MGD 1 MLD	HACCP ISO 9001 ISO 14001 AS 4801 OHS RWQMP (Victoria regulations)	2010 for regulatory approval	HACCP plans supplied by Kris Fumberger from City West Water Australia in 2010
CWW Altona, Melbourne, Victoria, Australia	Unrestricted irrigation (e.g., for public and private open spaces, dust suppression, street cleaning) Industrial uses (e.g., washdown water, boiler use, firefighting, cooling towers, high-pressure cleaning, and pump flushing)	9 MLD			

Notes: AS OHS=Australian Standards for Occupational Health and Safety; CWW=City West Water; HACCP=hazard analysis and critical control points; ISO= International Standards Organization; OHSAS=Occupational Health and Safety Advisory Services; PUB=Public Utilities Board, Singapore; RWQMP=Recycled Water Quality Management Plan

4.2 Background

The 12 steps to develop a HACCP plan were outlined in the previous chapter. A summary of various utility HACCP plans citing specific examples is provided in this chapter to illustrate how the HACCP steps are implemented in practice. Some utilities have opted for the full 12-step approach in documenting their HACCP plans, whereas others have developed high level overview documents that reference various subordinate documents that contain the details. A concise overview of the steps of the reviewed HACCP plans is given in Table 4.2.

Table 4.2. HACCP Steps—Comments on Utility HACCP Plans

HACCP Step	Comments on Utility HACCP Plans
Assemble HACCP team	The number of members on each HACCP and the nature of the membership are fairly consistent across all the HACCP plans. There appears to be consensus as to which utility departments should be represented in the development of a HACCP plan.
Describe product	In most cases the product description merely cites recycled water guidelines and regulations and includes product specifications based on those documents. Therefore, it is usually a simple step to describe the recycled water product by referencing the relevant regulation or guideline.
Identify intended use	The intended use is often stated as part of the product description, particularly when the description is a reference to external guidelines. Uses vary across plans, and both intended and inadvertent uses are covered.
Construct flow diagram	The flow diagrams differ in the level of detail provided. Some show basic operations and process steps, whereas others contain detailed information on the supply system and instrumentation.
Verify flow diagram	All flow diagrams are verified to confirm their accuracy, although the level of formality varies across the plans. In some cases, there is a formal process of signing off on the diagram by signing the page where the diagram appears, whereas in other cases the diagram is approved as an inclusion within a plan.
Conduct a hazard analysis	The approach taken to hazard analysis differs widely across the utility HACCP plans. At the more sophisticated end, some plans involve a detailed risk assessment methodology that includes semiquantitative risk ranking to assess risks in both their controlled and uncontrolled state. At the simpler end, some plans simply list significant hazards and their associated controls.
Determine the CCPs	This is an area of more uniformity. Most utility HACCP plans contain similar CCPs because of the similar nature of the recycled water supply systems. Some plans also show QCPs to cover noncritical control processes, such as those in place to manage customer service expectations.
Establish critical limits	The critical limits vary among plans and are virtually scheme-specific. The critical limits vary depending on the nature of the treatment process and the level of control available to the utility. In some cases, regulatory requirements influence the choice of critical limits.
Establish a monitoring system	Monitoring procedures are consistent across the plans and typically involve online monitoring of critical limits with regular testing of other parameters. Most critical limit monitoring is linked to automated processes to protect recycled water users in the event of deviations outside of critical limits.

Table 4.2. HACCP Steps—Comments on Utility HACCP Plans *(continued)*

HACCP Step	Comments on Utility HACCP Plans
Establish corrective actions	Corrective actions are similar because of the similar nature of the recycled water supply systems and typically involve diverting water to storage until the process is brought back under control.
Validate and verify the HACCP plan	The validation and verification actions are similar across the plans. Validation largely draws from widely used validation guidance such as Title 22, USEPA, ETV, DVGW, NWRI, ONORM, or other credible sources. Verification typically involved internal and external auditing and cross-checking.
Establish documentation and recordkeeping	The documents and records kept are consistent across the utility HACCP plans. All the HACCP plans received were developed by organizations with ISO 9001 systems in place, and the documents were typically managed within the context of these ISO systems.

Notes: CCP=critical control points; DVGW=German Technical and Scientific Association for Gas and Water; ETV=environmental technology verification; HACCP=hazard analysis and critical control points; ISO=International Standards Organization; NWRI=National Water Research Institute, ONORM=Austrian Standards Institute; QCP=quality control points; USEPA=United States Environmental Protection Agency

Although all of the reviewed plans addressed the HACCP system in full, not all were structured according to HACCP. Some were aligned with other management systems, such as ISO 9001 Quality Management Systems, and others were aligned with guidance documents, such as the AG WR. In this way, the HACCP plans can be integrated with other management systems; for example, Melbourne Water has a management system framework that integrates the commonalities among the Recycled Water Quality Management System, the Drinking Water Quality Management System, and the Environmental and Public Health Management System into its IMS, based on ISO 9001. The more comprehensive HACCP plans include other relevant information such as recycled water supply agreements, agency roles and responsibilities, and regulatory requirements.

4.3 The HACCP Team

The composition of the HACCP team was pivotal to the development of the HACCP plan and ensuring team commitment was the first step in the HACCP process. The team generally consisted of between 10 and 20 persons from a range of disciplines, often including people external to the water utility when risk management, verification, or compliance activities were contracted out. For example, external laboratory personnel were often part of the HACCP team when water sampling and testing was undertaken by an external agency. In some instances, external consultants were utilized in the development of the plan, particularly when they had specialist expertise.

The HACCP team members from within the utility represented diverse areas of the organization, including the following departments:

- operations
- assets
- engineering
- planning
- trade waste
- customer services
- backflow prevention

- environmental management
- audit compliance
- research

Each individual in the team was included to contribute a specific area of knowledge, expertise, and skill to ensure that all areas of risk and control were covered in the HACCP plan while also ensuring practicality. The team was always listed in the HACCP plan including individual team member names and positions, and often the team member roles and contact details were included.

Some utilities documented in their HACCP plan the wider team that contributed to the development of the plan. For example, Yarra Valley Water tabulated:

- the core team members
- the wider team that contributed occasionally to a series of workshops
- the contributors external to the utility, such as the Department of Health

The plan also showed:

- the original team members involved in the development of the plan up front
- the current (smaller) HACCP team involved in ongoing maintenance and updating the plan

In many cases, some key coordinator or leader was identified, and the term HACCP Champion was used to describe that person. In general, key contact information for the HACCP team and HACCP plan overall was included. Example HACCP teams are given from two of the example plans in Tables 4.3 and 4.4.

Table 4.3. HACCP Team Membership—Allconnex Water Merrimac WWTP HACCP Plan

HACCP Team Member Position
Team Leader, Product Quality
Executive Coordinator, Treatment Operations
Team Leader, Environmental Management
Supervisor, Coombabah Wastewater Plant
Supervisor, Merrimac Wastewater Plant
Supervisor, Elanora Wastewater Plant
Supervisor, Beenleigh Wastewater Plant
Reuse Project Officer
Coordinator Process Audit and Research
Product Quality Technical Officer (Wastewater)
Product Quality Technical Officer (Recycled Water)
Process Audit and Research Technical Officer
Asset Manager, Wastewater Treatment Plants

Table 4.4. City West Water Werribee Employment Precinct Recycled Water HACCP Plan Development Core Team

Title	Role in HACCP
Manager, Water Innovation	HACCP team leader
Water Innovation Officer	HACCP team officer
Senior Operations Officer	Recycled water distribution system operational management
Water Quality Specialist	Water quality advice, HACCP specialist
Senior Officer, Water Assets	Asset performance
Compliance Coordinator	Principal maintenance contractor
Development Officer	Backflow prevention
Risk Management, Quality, and Insurance Officer	Corporate risk management

Note: HACCP=hazard analysis and critical control points

Reviewing all the HACCP plans together, the following roles or their equivalent appeared to be represented on many or most HACCP teams:

- HACCP Champion/Leader/Coordinator
- Water Quality Manager/Specialist/Senior Officer
- Operations/Treatment Manager/Senior Operator
- Asset Manager
- Trade Waste Officer/Manager

- Backflow Prevention Officer/Manager
- Planning and Development Officer
- Risk Management/Compliance Officer

4.4 Product Description

The recycled water supplied by the utility was usually described in detail explicitly to assist the risk management process. The product description often included a general summary of the treatment processes applied to the wastewater as well as the regulatory requirements that must be met, including the final product quality specifications, for example, the microbiological criteria.

The product description sometimes included information on inputs such as the quality of treatment chemicals applied to the wastewater and the quality of the raw wastewater feed product. It typically started with some very concise name or identifier that provided a general understanding of what the product was (see Table 4.5).

A more detailed product specification then typically followed (see Table 4.6). In many cases, this was supported by a few pages of general information, such as:

- scheme location
- scheme scale (capacity, range of flows and flux)
- catchment description, noting inputs
- site plan and maps showing general arrangements

Table 4.5. Example of Concise Summary Descriptions of Recycled Water

HACCP Plan	Product Summary Description
CWW—Altona RWQMP and HACCP Plan	Single-pass RO recycled water Dual-pass RO recycled water
Yarra Valley Water—Aurora Recycled Water HACCP Plan	The Aurora Recycled Water System produces and distributes Class A Water as described in Victoria EPA Publication 1015—Guidelines for Environmental Management: Dual Pipe Water Recycling Schemes—Health and Environmental Risk Management (EPA Victoria, 2005).
Singapore PUB—NEWater	NEWater is used primarily for direct nonpotable use and indirect potable use. For direct nonpotable use, NEWater is distributed to industries by the network system managed by the Water Supply (Network) Department, NEWater Demand Centre. For indirect potable use, NEWater is pumped into compounded reservoirs in Singapore to supplement the water supply.

Notes: CWW=City West Water; EPA=Environmental Protection Agency; HACCP=hazard analysis and critical control points; PUB=Public Utilities Board; RO=reverse osmosis

Table 4.6. Detailed Product Description—PUB Singapore NEWater Factory HACCP Plan

1. Product name	NEWater
2. Ingredients	High grade water
3. Important product characteristics	Refer to Product Specifications
4. How it is to be used	Direct nonpotable and indirect potable use
5. Packaging	Supplied through a distribution network
6. Shelf life	Newater supplied directly through distribution network managed by newater Demand Centre (Wireless Sensor Network)
7. Storage conditions	Ambient temperature (closure conditions)
8. Where it will be sold	Singapore
9. Labeling instructions	No
10. Special distribution control	Routine sampling and testing
11. Remarks	None

Note: WSN=Wireless Sensor Network

A detailed, technical water quality specification was usually provided for the raw material (see Table 4.7) and treated product (see Table 4.8). Some plans include information on pathogen log reduction requirements (see Table 4.9).

Table 4.7. Design RWTP Feed Water Quality—South East Water Boneo RWQMP

Parameter	Range	Average Expected
BOD_5	2–5 mg/L	3 mg/L
Suspended solids	2–10 mg/L	5 mg/L
Turbidity	2–8 NTU	3 NTU
Total nitrogen	5–10 mg/L	<8 mg/L
Total phosphorus	8–12 mg/L	10 mg/L
Ammonia nitrogen	0.1–3 mg/L	<1 mg/L
Total dissolved solids	500–800 mg/L	<800 mg/L
Temperature	15–22° C	18° C
pH	6–9 pH units	6–9 pH units

Notes: BOD=biochemical oxygen demand; NTU=nephelometric units

Table 4.8. Detailed Product Specification—PUB Singapore NEWater Factory HACCP Plan Summarizing NEWater Quality and Corresponding USEPA/WHO Water Quality Standards

Water Quality Parameters	NEWater	USEPA/WHO Standards
PHYSICAL		
Turbidity (NTU)	<0.5	5/5
Color (Hazen units)	<5	15/15
Conductivity (µS/cm)	<150	--/--
pH value	7.0–8.5	6.5–8.5/--
Total dissolved solids (mg/L)	<100	500/1000
TOC (mg/L)	<0.5	--/--
Total alkalinity ($CaCO_3$; mg/L)	<50	--/--
Total hardness ($CaCO_3$; mg/L)	<20	not available
CHEMICAL (mg/L)		
Ammoniacal nitrogen (as N)	<1.0	--/1.5
Chloride (Cl)	<20	250/250
Fluoride (F)	<0.5	4/1.5
Nitrate (NO_3)	<15	--/--
Silica (SiO_2)	<3	--/--
Sulphate (SO_4)	<5	250/250
Residual chlorine (Cl total)	<2	--/5
Total trihalomethanes	<0.08	0.08/--
METALS (mg/L)		
Aluminum	<0.1	0.05–0.2/0.2
Barium (Ba)	<0.1	2/0.7
Boron (B)	<0.5	--/0.9
Calcium (Ca)	<20	--/--
Copper (Cu)	<0.05	1.3/2
Iron (Fe)	<0.04	0.3/0.3
Manganese (Mn)	<0.05	0.05/0.5
Sodium (Na)	<20	--/200
Strontium (Sr)	<0.1	--/--
Zinc (Zn)	<0.1	5/3
BACTERIOLOGICAL		
Total coliform bacteria (counts/100 mL)	not detectable	not detectable
Enterovirus	not detectable	not detectable

Sources: USEPA and WHO
Notes: NTU=nephelometric turbidity units; TOC=total organic carbon; WHO=World Health Organization; USEPA=United States Environmental Protection Agency

Table 4.9. Pathogen Log Reduction Requirements—South East Water Boneo HACCP Plan Based on Australian National and Victoria State Guidelines

Water Use	Virus Log Reduction Target	Protozoa Log Reduction Target	Bacteria Log Reduction Target
Municipal use: open spaces, sports grounds, golf courses, dust suppression, OR unrestricted access and application (national guidelines)	5.0	3.5	4.0
Commercial food crops consumed raw or unprocessed (national guidelines)	6.0	5.0	5.0
Dual reticulation median log reduction required (state guidelines)	7	6	--
Dual reticulation lower limit log reduction required (cease supply; state guidelines)	6	5	--

Reviewing all the HACCP plans together, the following key features of product descriptions appeared in most HACCP plans:

- concise product description
- product specifications as a series of table rows
- overview description from source to point of use as text, maps, and diagrams
- detailed technical description as a table of water quality criteria
- treatment chemicals applied

4.5 Intended Use

The statement of intended use lists how the recycled water is to be used and can include who is going to be using the recycled water and for what purpose. This statement may also indicate uses for which the water is not suitable. It often makes reference to the relevant regulations and guidelines.

For instance, for the City West Water Altona RWQMP and HACCP plan, the description of intended use was:

- Single-pass RO recycled water: unrestricted access irrigation quality water for the uses of irrigation of public and private open spaces, dust suppression, and street cleaning
- Dual-pass RO recycled water: industrial uses, including washdown water, boiler use, firefighting, cooling towers, high-pressure water jetting (for site cleaning), and pump flushing

In some cases, the intended use description was very detailed. For instance, for the Yarra Valley Water Aurora HACCP plan, the intended use description is given in Figure 4.1.

In general, any use could form part of a HACCP plan. The most common uses given in HACCP plans were as follows:

- irrigation of parks and gardens
- irrigation for agriculture and grazing pasture
- feed water for boilers and cooling towers
- dust suppression and street cleaning
- firefighting
- domestic use, including garden use and toilet flushing

The EPA Dual Pipe Water Recycling Guidelines (EPA, 2005) lists acceptable uses of Class A recycled water, including:

- Domestic garden watering (including vegetable gardens)
- Domestic clothes washing (with dedicated fittings to washing machine) and toilet flushing (including both toilets and urinals)
- Domestic outdoor use (excluding unintended uses) but including washing of cars and filling of ornamental ponds and water features
- Irrigation of public open spaces
- Water carters and water carter users
- Livestock and pet consumption (except for pigs)
- Grazing pasture for domestic animals excluding pigs
- Firefighting, dust suppression, and street cleaning
- Cooling tower

Industrial uses including:

- Material washing
- Process rinse water
- Crate and pallet washing
- Hardstand and vehicle washing
- Industrial fire protection
- Cooling
- In production line
- pH adjustment
- Boiler or cooling tower feed water supplement

For any other intended uses not listed previously, prior approval must be sought from Yarra Valley Water, EPA, and DHS before Class A recycled water can be used.

Class A recycled water is not considered acceptable for the following uses:

- Drinking, cooking, or other kitchen purposes
- Bathing and showering
- Filling or topping up swimming pools and external spas
- Children's water toys and other recreation involving water use

The DHS has not undertaken a detailed assessment of the health risk posed by Class A recycled water in evaporative air conditioners and therefore advises that it does not consider the use of Class A recycled water in evaporative air conditioners as an acceptable use at this stage.

Figure 4.1. Description of intended use—Yarra Valley Water Aurora recycled water HACCP plan.

4.6 Flow Diagram

The flow diagrams generally showed the entire process from source and collection of sewage through point of use. The diagram typically included information such as wastewater treatment processes, storage, and steps (see Figure 4.2). Each feature was shown by a specific symbol, and in some cases, a key was used to represent these symbols. In other cases, pictorial representations were used to show particular flow diagram process steps. The diagrams sometimes included key features such as control valves, pump stations, chemical feed points, and various possible flow pathways. The flow diagram was used for the hazard analysis step, and the test for an adequate flow diagram is that it should contain significant detail to enable identification of potential hazard entry and complete the risk assessment.

Once the CCPs were determined, these were often included on the flow diagram too. This breaks the linear process of steps in the HACCP system in that the flow diagram is completed prior to the assessment of risk or the identification of CCPs; however, the diagram can simply be updated following the completion of the identification of CCPs.

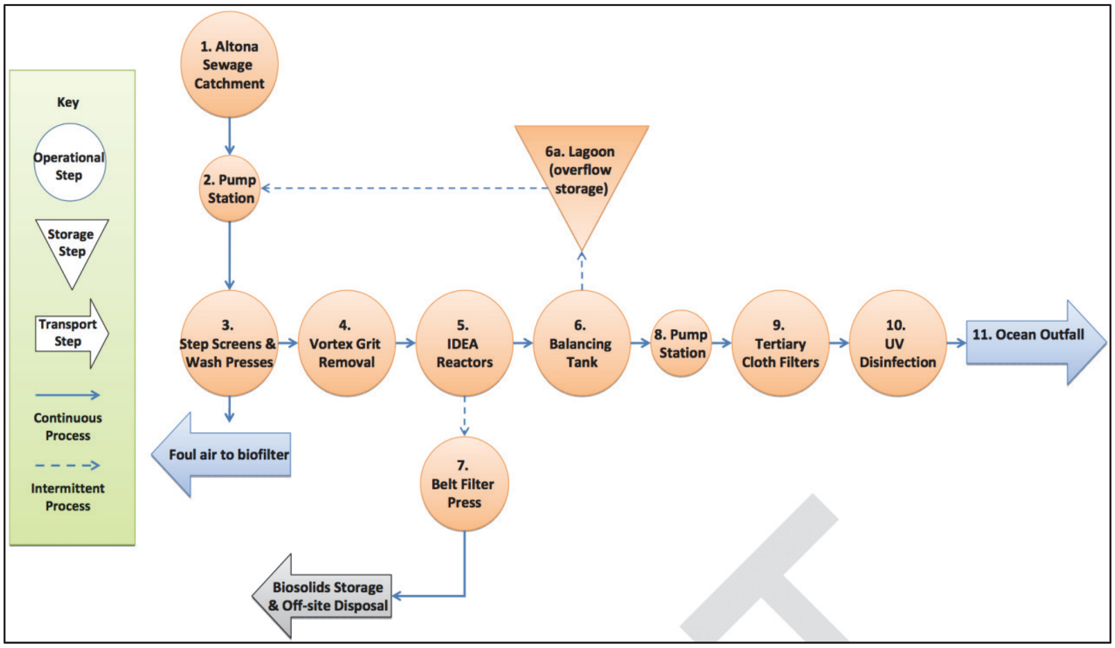
Many utility HACCP plans contain a schematic diagram of the recycled water reticulation system overlaid on a map, as noted in Section 4.4. Sometimes that schematic appeared in the HACCP plan along with the flow diagram rather than with the product description.

Flow diagrams typically showed the following features:

- operational steps
- storage steps
- transport steps

Flow diagrams sometimes showed the following features:

- chemical inputs
- alternative inputs (e.g., tankered waste)
- rework flows in the event of process failure
- process water flows, such as carrier water and backwash water
- side streams
- bypass options that existed within the pipework
- product end uses
- CCPs
- critical limit monitoring points
- sampling points



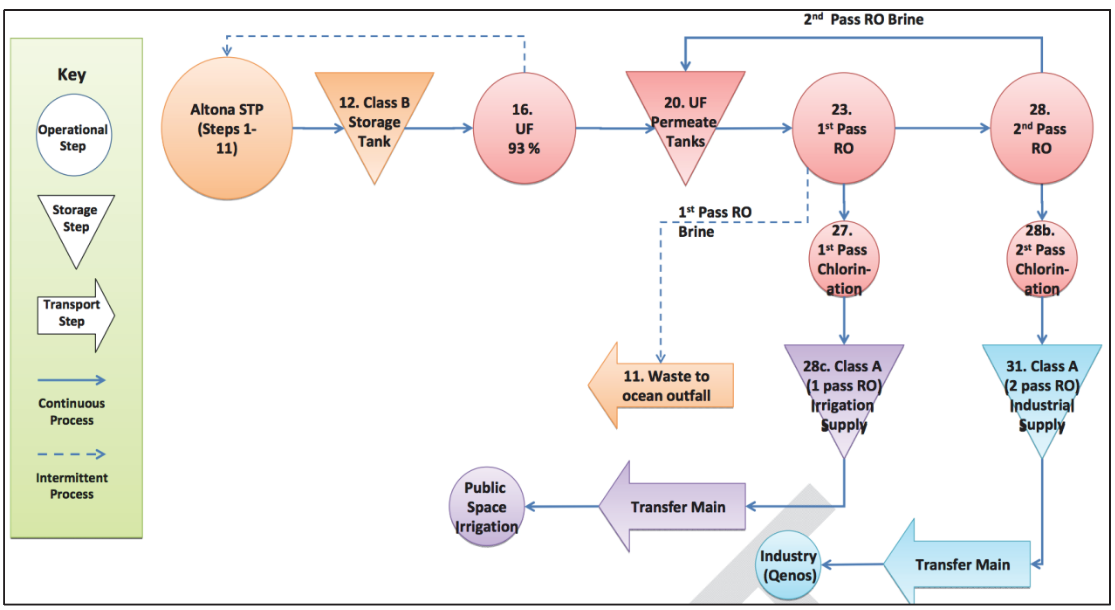
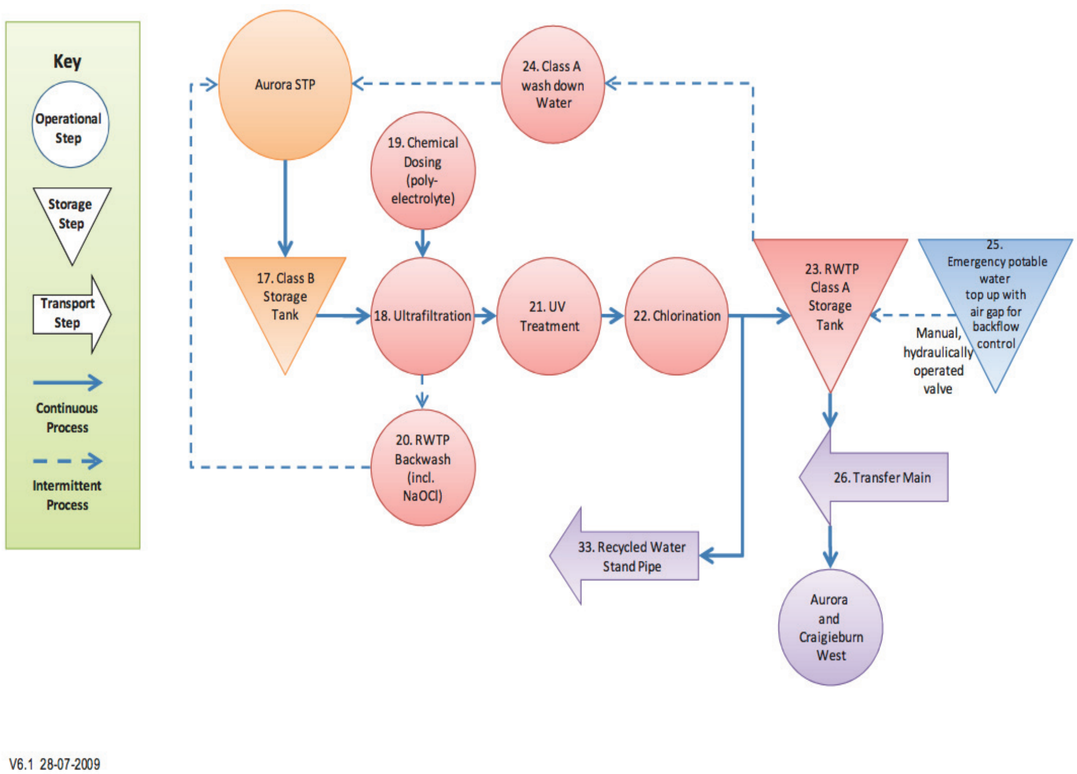


Figure 4.2. Example of flow diagram from City West Water.

Note: The upper diagram shows the current WWTP, and the lower diagram shows the RWTP.

4.7 Flow Diagram Verification

Various approaches were taken to the formal verification of the accuracy of the process flow diagram. A physical walkthrough of the process was sometimes undertaken as part of process flow diagram verification, as recommended in HACCP, but typically the verification was based on approval and sign off by a knowledgeable person or persons. The most formal approach for verification involved having accountability for signing off on the flow diagram along with the image of the flow diagram (see Figure 4.3). In most cases, the flow diagram was considered to be verified by the approval process associated with the whole HACCP plan within which the flow diagram was embedded. In other cases, the accuracy of the flow diagram was assessed as part of the risk assessment workshop, with those present being asked to formally endorse that, to their knowledge, the diagram was accurate.



Original process flow charts were prepared by [name withheld] on 10 January 2006. These were updated in October 2008 by [name withheld] and again in August 2009 by [name withheld]. Process flow charts were approved by:

[name withheld] Manager Water Quality Infrastructure Planning Date:……………………
Signature..……………………………………

[name withheld] Manager Treatment Plant Planning Date:……………………
Signature..……………………………………

Figure 4.3. Example of an approved flow diagram—Yarra Valley Water Aurora recycled water HACCP plan showing version number, authorship, and signatory details.

4.8 Hazard Analysis

The hazard analysis step involved hazard identification as a minimum and usually also involved risk assessment and identification of control measures. Hazard identification was conducted by the HACCP team by working through the process steps identified in the verified process flow diagram. The assessment involved a facilitated workshop process to capture the detailed results and summary tables. Each process step was examined to determine the events by which hazards could enter the system or by which their removal from the system would be compromised. The term hazardous events was commonly used to describe these causal events. The team performed this step using professional judgment rather than hard numbers (i.e., based on their knowledge and experience of the system along with historical data, if any). In some cases, the team used a facilitated workshop to develop consensus scores purely for discussion, and in other cases, all workshop participants individually scored all risks with the risk scores given as the average of the group.

The hazards were generally categorized as microbial, chemical, and physical; sometimes, there were categories at a more detailed level. The risk associated with each identified hazard was often assessed using a semiquantitative scoring approach involving rating both the likelihood and consequence of the hazardous event (see Figure 4.4). As part of the hazard analysis, the HACCP team identified control measures (also called preventive measures) that would eliminate or reduce the hazard to an acceptable level. Many risk assessments included an assessment of both maximum and residual risk (see Table 4.10), whereas others only assessed residual risk (Table 4.11).

Each HACCP team adopted its preferred approach, and each plan summarized the hazard analysis in different forms; however, a number of common types of hazardous events were found in all or most HACCP plans, including, in the broad sense:

- discharge in sewer catchment
- inadequate sewage treatment
- Blue-green algae (BGA) in raw feed product from storage
- chemical overdosing or underdosing for any chemical dosing process
- filter breakthrough
- disinfection failure
- pipe or tank failure
- cross-connection or backflow

Column headings appearing in the HACCP risk assessment tables typically included the following:

- Process step
- Hazard
- Hazardous event or source and cause of hazard
- Likelihood of risk
- Consequence of risk
- Preventive or control measures
- Residual risk ranking and sometimes maximum risk ranking

In most HACCP plans, the highest risks were singled out for special attention (see Tables 4.12 through 4.14). Risks often rated as high in many HACCP risk assessment tables, included the following causes:

- poor quality sewage influent
- sewage treatment plant (STP) failure
- inadequate filtration or disinfection
- backflow and cross-connection

Table 4.10. Example of Maximum and Residual Risk Assessment: Broad-Scale Hazard Identification and Risk Assessment for Wastewater and Public Health—SA Water Glenelg–Adelaide Recycled Water Scheme, Recycled Water (Supply) Management Plan

Hazard or Hazardous Event	Maximum (Unmitigated) Risk			Residual Risk		
	Likelihood	Impact	Rank	Likelihood	Impact	Rank
Human exposure to recycled water containing viruses	5	3	extreme	2	2	low
Human exposure to recycled water containing protozoa (and helminths)	5	3	extreme	2	2	low
Human exposure to recycled water containing bacteria	5	3	extreme	2	2	low
Chemicals in the wastewater	5	3	extreme	2	2	low
Cross-connections between recycled water and drinking water system	3	4	extreme	1	2	low
Wastewater entering the receiving environments	4	4	extreme	2	1	low

Table 4.11. Residual Risk Assessment for Chlorination CCP Process Step—South East Water Boneo RWQMP

Potential Hazard	Preventative Measure	Likelihood	Consequence	Residual Risk	Critical or Operational Limit
Under- and overdosing—pump failure	Flow switch alarms, installed standby, PLC alarms	3	5	High	
Wrong chemicals used	Supervised tank filling and clearly labeled tanks and delivery lines				
pH out of optimal disinfection range	Final effluent pH meter				Target pH range 6.5–8.0
Flow rate and flow pace dosing not in correct ratio (incorrect setting or undersized dose pump), link to NH_3 as unknown demand	Total plant flow rate, calibration of dosing pumps				
Ammonia higher than feed level, affecting Cl dose and demand	Free Cl meter, assessment on NH_3 level				Refer to STP HACCP. Feed water<1 mg/L NH_3.
Minimum temperature	Temperature meter in membrane feed				
Excessive Cl	Cl meter in final product water				Free chlorine 1–1.5 mg/L
Broken tank baffles	Maintenance and inspection procedures				
Not achieving required CT	Cl meter feedback, algorithm for CT calculation				

Notes: CT=contact time (for disinfection using chlorine); HACCP=hazard analysis and critical control points; PLC=programmable logic controller; STP=sewage treatment plant

Table 4.12. Summary of Hazards and Risks Rated Medium or Higher—SA Water Glenelg–Adelaide Recycled Water Scheme, Recycled Water (Supply) Management Plan

Location	Risk #	Hazard or Hazardous Event	Residual Risk
Glenelg catchment	3	Toxic chemical in trade waste discharges sufficient to upset GWWTP biological activated sludge process	medium
	6	Increasing recycled water salinity impacting acceptability for irrigation	medium
Glenelg WWTP	9	Failure of secondary treatment at GWWTP caused by toxic chemicals in sewage adversely impacting biomass	high
	11	Gross solids carryover from GWWTP blocking 10 mm screens at outlet of chlorine contact tank	high
	29	High/low ph in UF chemical backwash water recycled to head of GWWTP	medium
	40	Elevated ammonia concentration in feed water	medium
Glenelg RWTP	20	Leakage of Class B effluent from feed water storage	medium
	27	UF membrane skid fails PDT	medium
	28	Spillage or leakage of UF cleaning chemicals	medium
	31	Failure of multiple UF skids to pass PDT	medium
	32	UF skid instrument failure	medium
	36	UV transmission of filtered, treated wastewater outside of range for which equipment has been validated	medium
	37	Inability to maintain UV RED caused by fouling of quartz tubes	medium
	39	Failure to maintain CT>20 mg/min/L	medium
	45	Leakage of recycled water and contamination of local groundwater or waterways	medium
	47	Failure of plant SCADA or plcs	medium
Trunk main	4, 6	Burst or damaged pipe main exposing people to recycled water	medium
	5	Burst or damaged pipe main contaminating land or aquatic environments with recycled water	medium
	7	Damaged pipe leaking and contaminating land or aquatic environments with recycled water	medium
	8	Accidental or deliberate cross-connection of recycled water pipeline with drinking water reticulation main	medium

Table 4.12. Summary of Hazards and Risks Rated Medium or Higher *(continued)*

Location	Risk #	Hazard or Hazardous Event	Residual Risk
Ring main	10, 12	Burst or damaged pipe main exposing people to recycled water	medium
	11, 13	Burst or damaged pipe main contaminating land or aquatic environments with recycled water	medium
	14	Accidental or deliberate cross-connection of recycled water pipeline with drinking water reticulation main	medium

Notes: CT=contact time (for disinfection using chlorine); GWWTP=Glenelg wastewater treatment plant; PDT=pressure decay test; PLC=programmable logic controller; RWTP=recycled water treatment plant; SCADA=supervisory control and data acquisition; UF=ultrafiltration; UV RED=ultraviolet reduction equivalent dose; WWTP=wastewater treatment plant

Table 4.13. Potential Hazards from Collection to Treatment Assessed as Significant Risks—Yarra Valley Water Aurora Recycled Water HACCP Plan

Step	Inputs	Potential Hazard	Cause	Preventive Measure
Sewer catchment	Household wastewater inputs	Microbial (pathogens)	Enteric, respiratory, wound, ocular, and aural pathogens shed by feces	Controlled downstream in STP and RWTP steps
	Household wastewater inputs	Chemical (hazardous)	Hazardous chemicals deposited in sewer by householders, illegally in some cases	Education and awareness program Fines for illegal dumping Dilution in sewer system
	Commercial wastewater inputs	Chemical (hazardous)	Hazardous chemicals deposited in sewer by commercial operations, illegally in some cases	Trade waste agreements and auditing (for commercial) Education and awareness program Fines for illegal dumping
Secondary sewage treatment (IDEA including balancing tank)	Coarse-screened, chemical-amended municipal sewage and tertiary disinfected sewage from the winter storage	Microbial (pathogens)	Poor performance of process for a range of possible reasons leading to reduced removal of pathogens; causes could be over- or under-aeration, inadequate residence time, or inappropriate sludge recycling and wastage rates	Robust process design Preventative maintenance of mechanical, electrical, and physical components
		Chemical (P, metals, organics, algal toxins)	Same as previous but for P, metals, and organics Winter storage yields excess algal toxins	Same as previous P removal Selective use of storage Monitoring of algal cell counts

Table 4.13. Potential Hazards from Collection to Treatment Assessed as Significant Risks—Yarra Valley Water Aurora Recycled Water HACCP Plan *(continued)*

Step	Inputs	Potential Hazard	Cause	Preventive Measure
Tertiary sewage treatment (alum dosing and filtration through sand filter)	Secondary treated municipal sewage, alum and NaOH	Microbial (pathogens)	Wrong chemical introduced or process not properly controlled, leading to overload of downstream processes	Chemical QA/QC PRP, turbidity monitoring of effluent P analysis
	Alum dosing secondary treated sewage and manual naocl dosing during backwash			Calibrate dosing pumps; perform drop test on dosing pumps using the calibration cylinder on dosing pumps. Initially, tertiary filters are likely to be lightly loaded filters and therefore have time to monitor filter performance. Advanced training required to identify these types of hazards—training on-site and procedure development
		Chemical (P and hazardous)	Excess of wrong chemical introduced, leading to contamination of recycled water with some other substance Process not properly controlled, leading to breakthrough or bypass of P Causes could include wrong or poorly maintained media, poor hydraulic operation, or insufficient ripening (bed settling and backwash water flushing).	Chemical QA/QC prerequisite program, P analysis Calibrate dosing pumps—perform drop test on dosing pumps using the calibration cylinder. Robust process design Preventative maintenance of mechanical, electrical, and physical components Possibility of wrong media managed by the construction contract's defect liability period Ensure backwashing durations are conservatively timed to ensure effective ripening occurs.

Table 4.13. Potential Hazards from Collection to Treatment Assessed as Significant Risks—Yarra Valley Water Aurora Recycled Water HACCP Plan *(continued)*

Step	Inputs	Potential Hazard	Cause	Preventive Measure
First UV disinfection	Treated sewage effluent	Microbial (pathogens)	Poor physical influent water quality leading to inadequate uv inactivation caused by poor water quality (excess particles or excess uv absorbers enter uv plant, leading to pathogen shielding and breakthrough or inadequate light penetration)	Upstream processes, particularly the secondary and tertiary treatment processes Monitor turbidity. Monitor transmissivity trends of the UV, particularly trends for alum overdosing. Monitor alum dosing.
		Microbial (pathogens)	Poor performance of process for a range of reasons leading to reduced removal of pathogens; causes could be lamp failure, inadequate warm-up period, ballast failure, power failure or low lamp power, dirty lamps, or excessive flow rate through unit	Robust process design Preventative maintenance of mechanical, electrical, and physical components UV control systems should identify site testing of UV control system—change of flow with respect to number of lamps switching on and off. Validation of SCADA alarms
UF	Disinfected tertiary treated sewage effluent (Class B Recycled Water), alum, polyelectrolyte, NaOH, HCl, and cleaners	Microbial (pathogens)	Poor physical performance of process for a range of reasons leading to reduced removal of pathogens; causes could be membrane module detachment, membrane rupture, wrong membrane, or accidental bypass	Robust process design (refer to design specifications) Preventative maintenance of mechanical, electrical, and physical components Routine effluent monitoring
		Microbial (viral pathogens)	Poor chemical performance of process for a range of reasons leading to reduced removal of pathogens; causes could be wrong or inadequate chemical dosed or excessive head loss or flow rate	Robust process design Preventative maintenance of mechanical, electrical, and physical components Chemical QA/QC PRP Routine effluent monitoring
		Microbial (pathogens)	Carryover of cleaning water to treated side	Divert to waste after filter change. SOP Backwash system prior to removal of membranes and following replacement.

Table 4.13. Potential Hazards from Collection to Treatment Assessed as Significant Risks—Yarra Valley Water Aurora Recycled Water HACCP Plan *(continued)*

Step	Inputs	Potential Hazard	Cause	Preventive Measure
Second UV unit	Ultrafiltered, tertiary treated disinfected sewage effluent	Microbial (pathogens)	Poor physical influent water quality leading to inadequate uv inactivation caused by poor water quality (excess particles or excess uv absorbers enter uv plant, leading to pathogen shielding and breakthrough or inadequate light penetration)	Control of upstream processes, particularly the secondary and tertiary treatment processes and uf plant SOP to be developed where appropriate
		Microbial (pathogens)	Poor performance of process for a range of reasons leading to reduced removal of pathogens; causes could be lamp failure, inadequate warm-up period, ballast failure, power failure or low lamp power, dirty lamps, or excessive flow rate through unit	Robust process design Preventative maintenance of mechanical, electrical, and physical components
Chlorination process	Ultrafiltered, tertiary treated disinfected sewage effluent and NaOCL	Microbial (pathogens)	Inadequate chemical dosing for a range of possible reasons leading to reduced removal of pathogens and residual; causes could be wrong or inadequate chemical dosed, dosing system failure, empty chlorine tanks, PLC error, or other electrical or mechanical failure	Robust process design Preventative maintenance of mechanical, electrical, and physical components Chemical QA/QC PRP Online free chlorine analysis Daily site testing with handheld Hach test kit (*Critical*)
		chemical (hazardous)	Excess of wrong chemical introduced leading to contamination of recycled water with some other substance	Chemical QA/QC PRP Online free chlorine analysis Daily site testing with handheld Hach test kit

Notes: IDEA=intermittently decanted extended aeration; P=phosphorus; PLC=programmable logic controller; PRP=prerequisite program; QA/QC=quality assurance/quality control; RWTP=recycled water treatment plant; SCADA=supervisory control and data acquisition; SOP=standard operating procedure; STP=sewage treatment plant

Table 4.14. Key Risks and Controls—City West Water Werribee Employment (Technology) Precinct Recycled Water HACCP Plan

Key Risks	Key Controls
Supply of Treated Recycled Water from Melbourne Water	
Inadequate treatment objectives	Trade waste agreements and Sewage Quality Management System (CWW)
Off-specification water caused by treatment failure	Melbourne Water RWQMP (incorporating HACCP plan)
Residual contaminants in sewage	HACCP plan for Western Treatment Plant (MWW)
Toxicity levels in sewage affecting process	Integrated Sewage Quality Management System (CWW Trade Waste HACCP plan) to address recycled water quality requirements Cessation of supply in event of detection or suspicion of noncompliant parameters (MW) Melbourne Water RWQMP (incorporating HACCP plan) MW's Class A RWQMP covers the processes of plant operation. Ongoing review program
CWW Recycled Water Storage and Distribution to Customers	
Contamination of recycled water from emergency events, construction or maintenance (CWW)	Construction protocols and inspection standards
Operational failure (CWW) resulting in • water retention in tank caused by operational failure • water retention in pipeline Customers may not be able to utilize the water resource for extended period.	System monitoring and auditing Operation and maintenance procedures Incident and Crisis Management Plan Contingency management plans O&M procedures
Biofilm sloughing	System monitoring and auditing
Impacts on surrounding environment from infrastructure failures and maintenance events (e.g., mains flushing, burst)	Operation and maintenance procedures Incident and Crisis Management Plan Contingency management plans Maintenance and operation procedures
Customer End Use	
Backflow	Backflow prevention device Training and education for plumbers and customer education Recycled water plumbing guide Plumbing and drainage standards Inspection, monitoring, and auditing (CWW infrastructure/client recycled water system) Regional and customer EIPs SOP for relevant process/operation Maintenance and operation protocols

Notes: CWW=City West Water; EIP=environmental improvement plan; HACCP=hazard analysis and critical control points; MW=Melbourne Water; MWW=Western Treatment Plant; O&M=operation and maintenance; RWQMP=Recycled Water Quality Management Plan; SOP=standard operating procedure

Likelihood Ranking	Probability/Frequency
A	**Almost certain** The event is expected to occur in most circumstances. The event could occur daily.
B	**Likely** The event will probably occur in most circumstances. The event could occur weekly.
C	**Possible** The event should occur at some time. The event could occur monthly.
D	**Unlikely** The event could occur at some time. The event could occur annually.
E	**Rare** The event may occur only in ***exceptional*** circumstances. The event could occur once in five years.

Consequence Ranking	Consequence
1	**Insignificant** No injuries, low financial loss
2	**Minor** First Aid Treatment, on-site release immediately contained, medium financial loss
3	**Moderate** Medical treatment required, no site release contained with outside assistance, high financial loss
4	**Major** Extensive injuries, loss of production capability, off site release with no detrimental effects, major financial loss
5	**Catastrophic** Fatality, toxic release off site, huge financial loss

Significance		Consequence				
		1	2	3	4	5
Likelihood	A	Medium	Significant	Significant	High	High
	B	Medium	Medium	Significant	Significant	High
	C	Low	Medium	Significant	Significant	Significant
	D	Low	Low	Medium	Medium	Significant
	E	Low	Low	Medium	Medium	Significant

Figure 4.4. Example of risk ranking criteria—City West Water Altona recycled water treatment plant HACCP plan.

4.9 CCPs and Critical Limits

CCPs (steps in the system when a control measure is critical to maintain the safety of the recycled water) were typically found in the recycled water treatment plant (RWTP) and sometimes up- and downstream of the plant (see Table 4.15). The CCPs could in theory be process steps, operations, or procedures. In general, significant hazards were explicitly shown to be controlled at a CCP. The CCPs were often marked on the process flow diagram after the CCP identification process (as noted in Section 4.6).

In addition to a CCP, some steps in some HACCP plans were termed QCPs, steps in the system when a control measure was essential to maintain the quality of the recycled water as distinct from protecting user safety (see Table 4.16). The term QCP was not used for control points relating to health-based hazards, and in some HACCP plans only CCPs were identified. In addition to CCPs and QCPs, in some HACCP plans PRPs or supporting programs were identified as being responsible for controlling some hazards.

For each CCP, and often for QCPs and PRPs too, a measurable parameter was established for process monitoring. For CCPs it was necessary to define a critical limit. The critical limit was determined using industry reference to some objective source as part of validation (see Section 4.11), which called up evidence such as standards, expert knowledge, experience, and historical performance. In some plans environmental CCPs were also defined (see Table 4.17).

Table 4.15. CCPs and Critical Limits—Yarra Valley Water Aurora Recycled Water HACCP Plan

CCP	Step	Limit
1	Sewer catchment	Refer to trade waste system.
2	IDEA (including balancing tank)	Presence of sludge blanket Cell count of BGA according to DSE alert levels
3	Alum dosing	6.0<pH<8.5 Tertiary filter turbidity median 2 and maximum 4 NTU Breach of chemical QA/QC procedures
4	Media sand filtration	Tertiary filter turbidity median 2 and maximum 4 NTU
5	First UV unit at STP	UV dose>90 mJ/cm^2 UVT>60% Flow rate>522 m^3/h Lamps operational>80%
6	UF unit	Feed flow rate: lower limit 66.0 m^3/hr; upper limit 109.0 m^3/hr Feed temperature: lower limit 11° C; upper limit 39° C DIT flow rate upper limit: 249 L/hr Permeate turbidity upper limit: 0.14 NTU Maximum transmembrane pressure upper limit: 92 kPa
7	Second UV unit	UV intensity lower limit: 74 W/m^2 UVT lower limit: 66% Feed flow rate: lower limit 66.0 m^3/hr Upper limit 109.0 m^3/hr Any lamp failure
8	Chlorination unit	pH: lower limit 6.1; upper limit 8.9 Free chlorine: lower limit 0.38 mg/L CT lower limit: 4.5 mg/min/L Temperature: lower limit 11° C; upper limit 39° C
9	Urban reticulation system	Audit failure (all works should comply with relevant regulations and requirements) Detection from customer complaints All water carters must be licensed.

Table 4.15. CCPs and Critical Limits—Yarra Valley Water Aurora Recycled Water HACCP Plan *(continued)*

CCP	Step	Limit
		Community education and awareness program
		No use of sewer repair crews or tools in the repair of recycled water mains
10	End use	100% of community must understand the key messages.
		100% of fittings must be appropriate
		Detection of pathogens in monitoring
		Notification of waterborne illness
		Customer complaints
		Chlorine residual monitoring of recycled water indicates possibility of stagnant water
11	Water carting	Detection from customer complaints
		All water carters must be licensed.
		Community education and awareness program

Notes: BGA=blue-green algae; CT=contact time (for disinfection using chlorine); DIT=direct integrity testing; DSE=Department for Sustainability and Environment, Victoria, Australia; IDEA=intermittently decanted extended aeration; NTU=nephelometric turbidity units; QA/QC=quality assurance/quality control; STP=sewage treatment plant; UV=ultraviolet; UVT=ultraviolet transmissivity

Table 4.16. QC Points—City West Water Werribee Employment (Technology) Precinct Recycled Water HACCP Plan

CCP/QCP	Step	Limit
CCP1	MW Class A Recycled Water Plant	Water quality monitoring trigger values according to IRD-120
QCP1	Backflow into reticulation system from standpipes	>1 customer accessing recycled water without appropriate BPD
QCP2	Backflow into reticulation system from public open space	>1 customer accessing recycled water without appropriate BPD
QCP3	Backflow into reticulation system from commercial and industrial uses	>1 customer accessing recycled water without appropriate BPD

Notes: BPD=backflow prevention device; CCP=critical control point; IRD=InfraRed Detection; MW=Melbourne Water; QCP=quality control point

Table 4.17. CCPs—SA Water Glenelg–Adelaide Recycled Water Scheme, Recycled Water (Supply) Management Plan

CCP	Critical Monitoring Parameter	Alarm Limits	Critical Limits
Health-Related CCPs			
UF	Effluent turbidity	>0.15 NTU for >30 min continuously	>1.5 NTU 24 hr average >0.3 NTU for >30 min continuously >0.5 NTU for >30 min continuously
	Pressure decay test	>3.5 kPa/min	>4.8 kPa/min
UV disinfection	UV transmission	<54% for >60 min continuously	<50% for >60 min continuously
	UV dose	<50 mJ/cm^2 for >30 min continuously	<50 mJ/cm^2 for >60 min continuously
Chlorine disinfection	CT (free)	<20 mg/min/L for >30 min continuously	<20 mg/min/L for >60 min continuously
CCPs for Environmental Management			
Feed water storage	Underdrain sump high, high-high level alarm	Set points to be adjusted during commissioning	Confirmed environmental discharge defined by criteria from Water/Wastewater INCP (DOH)
Chemical storage/dosing	Bund sump level high, high-high, tank high, high-high and overflow, transfer/dosing pump no flow, dosing pump low flow alarms	Set points to be adjusted during commissioning	Confirmed environmental discharge defined by criteria from Water/Wastewater INCP
Recycled water storage	Underdrain sump high level alarm	Set points to be adjusted during commissioning	Confirmed environmental discharge defined by criteria from Water/Wastewater INCP
Trunk main	Trunk main pressure low alarms	Variable alarm levels calculated based on system operating conditions	Confirmed environmental discharge defined by criteria from Water/Wastewater INCP

Notes: CCP=critical control point; CT=contact time for chlorine disinfection; DOH=Department of Health; INCP=incident notification and communication protocol; UF=ultrafiltration; UV=ultraviolet

CCPs differed between plans both with respect to their identity and how they were described. Process steps often listed as CCPs in HACCP plans typically included the following:

- collection of the raw feed product
- chemical dosing
- filtration
- disinfection
- recycled water storage
- recycled water distribution
- recycled water end use

Critical limit values for CCPs were typically set for the following operational monitoring parameters:

- filtered water turbidity
- pressure decay rate during integrity testing
- UV dose
- oxidant disinfectant CT

4.10 Monitoring and Corrective Action Procedures

Each CCP, as well as many QCPs and some PRPs, was assigned a monitoring procedure to detect deviations outside of the critical (and sometimes target) range. For each monitoring procedure, a corrective action was developed to ensure that the CCP is brought back under control and unsafe water would not be supplied to the water users (see Tables 4.18 and 4.19). The corrective action was designed to protect recycled water users while the process was brought back under control. The monitoring procedure usually set out in detail the nature of the specific information that was being recorded.

In most cases, more than one limit was established to ensure the safety and quality of the product. There might be an operational or alert limit that is more stringent than the critical or shutdown limit at which the corrective action must be taken to protect recycled water users.

Because the monitoring and correction action process needed to ensure that unsafe water would not reach end users, parameters were often measured online. The monitoring would provide immediate indication to trigger corrective action. In many cases, the first part of the automated corrective action following any deviation from the critical limit was an automatic diversion or shutdown.

For monitoring, the HACCP plans or referenced procedures typically explained the following:

- What parameter is to be monitored
- How the parameter will be monitored
- When the analysis will take place
- Where the sample will be taken
- Who is responsible for ensuring that the monitoring takes place and results are recorded

For corrective actions, the HACCP plans or referenced procedures typically explained the following:

- what corrective action is required
- how the corrective action will be undertaken
- when the corrective action should take place after the alert trigger—time delay
- where the correction action will take place
- who is responsible for ensuring that the corrective action takes place and recording it

Table 4.18. Monitoring and Corrective Action for the Chlorination CCP—South East Water Boneo RWQMP

Chlorination CCP			
What	**pH**	**CT**	**Temperature**
Critical Limits/Alert Limits			
Critical limits	6.5–8	3.8 mg/min/L	<13˚ C
Monitoring Procedures			
How	pH sensor	free chlorine meter and flow meter	temperature sensor
When	continuous	continuous	continuous
Where	post-Cl contact tank	post-Cl contact tank	post-Cl contact tank
Who	operator	operator	operator
Corrective Actions			
What	divert water or shut down plant	divert water or shut down plant	divert water or shut down plant
How	PLC/SCADA with alarm	PLC/SCADA with alarm	PLC/SCADA with alarm
When	pH is out of limit	Cl residual is outside limit	temperature is outside limit
Where	upstream of Class A storage tank	upstream of Class A storage tank	upstream of Class A storage tank
Who	operator	operator	operator

Notes: CCP=critical control point; PLC=programmable logic controller; SCADA=supervisory control and data acquisition.

Table 4.19. Monitoring and Corrective Action—PUB Singapore NEWater Factory HACCP Plan

Process	Critical Limits	Monitoring Procedures & Frequency	Corrective Action
RO	Action Limit TOC<100 ppb TOC<110 ppb Shutdown Limit TOC<150 ppb	Online monitoring	1. Check TOC meter on-site. 2. Put any one RO train to recycle mode or blend feed water with potable water supply >110 ppb. 1. Put any one RO train to dump mode if TOC continues to increase >150 ppb. 2. Shut down plant (approved by plant/ general manager).
	conductivity <90 μS/cm conductivity <100 μS/cm conductivity <150 μS/cm	Online monitoring	1. Verify meter reading with lab test and check meter on-site. 2. Recycle RO permeate to filtrate tank or blend feed water with potable water supply >100 μS/cm. 1. Put RO train to dump mode if conductivity continues to increase >150 μS/cm. 2. Shut down plant (approved by plant manager).
UV disinfection	UV intensity/dose >60 mJ/cm^2	Online monitoring	1. Check UV system on-site. 2. Replace UV lamp.
Sodium hydroxide	pH 7.2–8.3	Online monitoring	1. Verify meter reading with lab test. 2. Increase/decrease the dosage instantly.

Notes: RO=reverse osmosis; TOC=total organic carbon; UV=ultraviolet

4.11 Validation and Verification

The overall objective of validation and verification is to provide checks and balances to ensure that HACCP plans are technically correct, implemented effectively in practice, and working as intended (see Table 4.20). Validation and verification mean different things in the HACCP system than in standard usage, which causes some confusion, and the two terms are often used interchangeably or not in strict accordance with the Codex HACCP.

Validation under HACCP means the same as the definition used by the USEPA and refers to objective evidence that ensures that process controls will, if operating as designed, control the hazards to the required extent. Validation was typically based on assembling evidence given in equipment design specifications, technical literature, industry guidelines and in-house studies. Validation often involves careful examination of the performance records of plants over extended periods. Theoretical knowledge of processes, access to past records, and an understanding of plant configuration is usually combined with published literature and guidance to arrive at particular limits. Validation often draws from widely used guidance such as Title 22 and USEPA guidelines (see Table 4.21). Evidence documents typically cited in setting validation included the following:

- equipment design specifications
- in-house performance knowledge and past records
- USEPA Membrane Filtration Guidance Manual (EPA 2005)
- USEPA UV Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule (EPA 2006)
- USEPA Guidance Manual: Disinfection Profiling and Benchmarking (EPA, 1999)
- AG WR: Managing Health and Environmental Risks (Phase 1) (NRMMC 2006)

Verifying that the HACCP plan is appropriate and effective generally involves audit, internal review, and record checks (see Table 4.22). The final testing of the treated water and the auditing of activities undertaken as part of a HACCP plan are typically covered under the umbrella of verification using the HACCP definition. Verification typically involves internal and external auditing and cross-checking. Systems are typically verified by several mechanisms:

- internal auditing
- audits by a third-party auditor, regulator, or certification body
- management review
- analysis of final water quality
- assessment of user perceptions and activities

Table 4.20. Validation and Verification Schedule for CCPs—Melbourne Water RWQMP

Process Step (CCP)	Activated Sludge	Maturation Ponds	Maturation Ponds	UV Plant Inadequate Disinfection	Chlorine Plant Inadequate Disinfection
Potential Hazard	Reduction in pathogen log removal capabilities; failure to meet Class A specification	Residence time in ponds not sufficient to allow for required log removal of pathogens	BGA toxins in recycled water product	Reduced level of inactivation of *Crypto-sporidium* and *Giardia*	Reduction in log removal values for pathogens
Critical Limit	Sludge blanket depth: 55E, 25W Critical limit: <0.5m below clarifier surface	L55E: <30ML/day bypass Pond 4 to Pond 5 (4 day average) L25W: no bypass from Pond 1 to Pond 2 allowed. A pond level limit of >2050 mm for 10 min in Pond 1 is applied.	According to retail water businesses' BGA risk management plans or risk assessments (specific alert and trigger levels are in place for different end uses).	UVT>45% turbidity <15 NTU flow <28.5 ML/d per channel dose >25mJ/cm^2 Deviations outside critical limits are allowed provided they are not sustained >3 min. Lamp life using manufacturers recommendations	Actual CT> required CT Required CT varies depending on temperature and chlorination mode (free or chloramination).

Table 4.20. Validation and Verification Schedule for CCPs—Melbourne Water RWQMP *(continued)*

Assumptions, Control Measures, and Monitoring	If process is meeting performance standard, sludge should not carry over the clarifier weir. Online (and alarmed) infrared sludge blanket monitoring is in place on each clarifier. A 5 min alarm delay is applied because of interference of pin flocs on the sludge blanket instrumentation. Online (and alarmed) turbidity monitoring on 25W clarifier output Process monitoring of flow set points for the ASPs Weekly monitoring of sludge characteristics in ASP Plume monitoring protocols, which outline the program for downstream monitoring should the critical limit be breached	Pathogen removal in the lagoon systems relies on sufficient detention time in the ponds to allow larger denser organisms to settle and for UV exposure to inactivate smaller, less dense organisms. Flow meters and flow balancing calculations Plume monitoring protocols outline the program for downstream monitoring should the critical limit be breached. Bypass volume for Pond 4 of the 55E lagoon is calculated using level monitoring and weir equation Q=72x1.45x (L-2.5) ^1.5/ 1000 x3600x24 Where: Q=bypass flow in ML/day L=water level	Provided toxin levels delivered <13 µg/L microcystin-LR toxicity equivalents, the water will not harm stock or humans through this mechanism. As advised by DSE, a relationship of 65,000 toxigenic cells/mL to 13 µg/L microcystin-LR toxicity equivalent is adopted. The monitoring frequency (usually daily Dec.–Mar.) is adequate given the relatively slow growth rate of toxigenic cyanobacteria (doubling times of many days). There is limited ability to control BGA outbreaks. Process engineers balance process performance and nutrient removal optimization to reduce the likelihood of an outbreak.	UV plant achieves 2 log *Crypto-sporidium* and *Giardia* Inactivation when operated within critical limits. PLC/SCADA monitoring and alarms Routine calibration and maintenance activities Routine visual inspection of equipment and instrumen-tation by operators Online cleaning devices Control interlocks SOP Management of change documentation	When operating within the critical limit, the chlorination plant reliably achieves 2 log reduction of viruses using either chloramine or free chlorine as the disinfectant. The effective detention basin volume is 6 ML as shown by tracer studies in commissioning. This volume is used by the control system to calculate actual contact time for CT control in chloramination mode. The control system uses a geometric mean of the chlorine dose concentration (mg/L) and the chlorine residual concentration at the free chlorine sample point to calculate the actual contact time for CT control in free chlorine mode. The effective detention basin volume used by the control system to calculate the actual contact time for CT control in free chlorine mode is 1.5 ML. The system is monitored using an online (calculated) CT analyzer, and temperature, total or free chorine, and flow are measured every minute. The system is alarmed on SCADA, and control interlocks shut down the ERW6 pumps in the event of a critical limit breach.

Table 4.20. Validation and Verification Schedule for CCPs—Melbourne Water RWQMP *(continued)*

Corrective Action	Invoke plume analysis protocol SOP. Review activated sludge plant operation and rectify or reduce flow throughput.	Invoke plume analysis protocol SOP Reduce hydraulic loading to the appropriate lagoon if possible.	Refer to BGA response protocol SOP.	Automatic plant shutdown Operators notify process engineers and locate fault Process engineers establish favorable corrective action and then reinstate plant	Automatic plant shutdown Operators notify process engineers, locate fault Process engineers establish favorable corrective action and then reinstate plant
Basis for Validation	Understanding of WTP activated sludge processes with respect to log removal rates DHS submission—basis for control limits and quality management response for 55E lagoon CCP DHS submission—basis for control limits and quality management response for Pond 1 to Pond 2 bypass in the 25W lagoon	Understanding of WTP maturation ponds DHS submission: accreditation of Class A recycled water supply from WTP to Werribee Irrigation District recycled water scheme (12/06/04) Assessment of LRV for 55E lagoon system WTP *Taenia* egg removal and *Taenia solium* risk assessment for the Werribee Irrigation District DHS submission: basis for control limits and quality management response for 55E lagoon CCP DHS submission: basis for control limits and quality management response for Pond 1 to Pond 2 bypass in the 25W lagoon	Melbourne Water acts on the advice of the retail water businesses with respect to BGA notifications and cessation of supply. This advice is set out in retail water businesses' risk management plans and risk assessments.	USEPA Ultraviolet Disinfection Guidance Manual	USEPA Alternative Disinfectants and Oxidants Guidance Manual 1999 USEPA Disinfection Profiling and Benchmarking Guidance Manual 1999, Appendix C
Validation	Historical data was used to evaluate treatment process capabilities in accordance with a range of technical guidelines.	Historical data was used to evaluate treatment process capabilities (including wet weather event benchmarking) in accordance with a range of technical guidelines.	Historical process monitoring of BGA outbreaks	USEPA validation testing using Tier 1 approach Plant design parameters and benchmarking Werribee Irrigation District Recycled Water Scheme UV Disinfection System Independent Validation Report	Werribee Irrigation District chlorination plant verification

Table 4.20. Validation and Verification Schedule for CCPs—Melbourne Water RWQMP *(continued)*

Citations		02/10/06 letter from EPA Victoria: Werribee Irrigation District recycled water scheme 25W approval 12/23/05 letter from DHS: 25W approval 12/13/05 letter from DPI: 25W approval 12/06/04 letter from DHS: Class A recycled water supply to Werribee Irrigation District, formal sign-off	Management Plan for Agricultural Water Supply During Blue-Green Algae Blooms in the Werribee Irrigation District (SRW), High Level Risk Assessment for Elevated Blue-Green Algae Levels in Recycled Water (CWW)		
Verification	Calibration of sludge blanket meters and turbidity sensors (25W) following SMIs Laboratory contract performance Review of maintenance records in HANSEN	Review of process parameters by process engineer during each wet weather event (when daily flow into the plant exceeds 1250 ML/day) Level sensor calibration and maintenance following relevant SMIs Review of maintenance records in HANSEN (internal audit) Laboratory contract performance	Review contingency plans Review KPIs and process performance WTP process meeting minutes	Review of process parameters by process engineer for customer report (monthly). Calibration and maintenance of instrumentation and equipment by SMIs. Review of maintenance records in HANSEN.	Performance testing (completed during commissioning). Review of process parameters by process engineer for customer report (monthly). Calibration and maintenance of relevant instrumentation and equipment using SMIs. Review of maintenance records in HANSEN.
Records	SCADA, plant logbooks, operator handover sheets, process meeting minutes	DHS submission and approval SCADA, plant logbooks, operator handover sheets, process meeting minutes	Laboratory results	SCADA, plant logbooks, operator handover sheets, process meeting minutes, laboratory results	SCADA, plant logbooks, operator handover sheets, process meeting minutes, laboratory results

Notes: ASP=activated sludge plant; BGA=blue-green algae; CCP=critical control point; CT=contact time (for disinfection using chlorine); CWW=City West Water, Victoria, Australia; DHS=Department of Human Services; DPI=Department of Primary Industries; DSE=Department for Sustainability and Environment, Victoria, Australia; HANSEN=proprietary asset management system; KPI=key performance indicator; LRV=log reduction value; NTU=nephelometric turbidity units; SCADA=supervisory control and data acquisition; SMI=standard maintenance instructions; SOP=standard operating procedure; SRW=Southern Rural Water; WTP=waste treatment plant; UV=ultraviolet; UVT=ultraviolet transmissivity

Table 4.21. Examples of Validation Evidence Bases

Item Validated	South East Water Boneo RWQMP	SA Water Glenelg–Adelaide Recycled Water Scheme, Recycled Water (Supply) Management Plan
Raw water quality targets	Chemicals entering the sewerage system are managed through a trade waste system that meets the requirements of ISO 22000.	
Recycled water treatment performance requirements		The microbial LRVs the treatment process needs to achieve are sourced from AGWR: Managing Health and Environmental Risks (Phase 1) (NRMMC, 2006). The microbial LRVs credited to each stage of the treatment process are consistent with those proposed in Gap Treatment Process Log Credit Summary (CityGreen 2008).
UF	The UF system is designed to achieve a 4 log reduction of protozoa and viruses in compliance with USEPA Membrane Filtration Guidance Manual (EPA, 2005).	Gap Treatment Process Log Credit Summary (CityGreen, 2008). USEPA Membrane Filtration Guidance Manual (EPA, 2005).
UV disinfection	The reference for the validation methodology was based on the validation protocols from USEPA Ultra Violet Disinfection Guidance Manual (EPA, 2006).	Gap Treatment Process Log Credit Summary (CityGreen, 2008) Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse (NWRI, 2012) UV Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule (EPA, 2006) Water Treatment and Pathogen Control (LeChevallier and Au, 2004)
Chlorine disinfection	USEPA Guidance Manual Disinfection Profiling and Benchmarking (EPA, 1999)	USEPA Guidance Manual: Disinfection Profiling and Benchmarking (EPA, 1999) WHO Guidelines for Drinking Water Quality, First Addendum to Third Edition, Volume 1, Section 7, Microbial Aspects (WHO, 2006) CT Project Report on Desktop Study(SA Water, 2008)

Notes: AGWR=Australian Guidelines for Water Recycling; AWWA=American Water Works Association; CT=contact time (for disinfection with chlorine); ISO=International Standards Organization; LRV=log reduction value; NWRI=National Water Research Institute; UF=ultrafiltration; USEPA=United States Environmental Protection Agency; UV=ultraviolet; WHO=World Health Organization

Table 4.22. Examples of Verification Activities

Yarra Valley Water Aurora Recycled Water HACCP Plan	CWW Werribee Employment (Technology) Precinct Recycled Water HACCP Plan	SA Water Glenelg–Adelaide Recycled Water Scheme, Recycled Water (Supply) Management Plan
RWTP treatment process—UF membrane challenge testing at periodic intervals. RWTP operational and verification monitoring. Monitor recycled water quality. 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 inspection measurement and test equipment.	Audit HACCP plan and its implementation. Review monitoring and corrective action records. Audit calibration and operation of monitoring equipment. Audit staff training/awareness. Verify hazards and control measures. Validate critical limits. Verify CCP/QCP monitoring and records. Verify corrective actions and records. Review recycled water (final product) quality monitoring. Review customer complaints. Review HACCP plan.	RWQMP Application site and receiving environment monitoring. Documentation and reliability. Data reporting and assessment. Satisfaction of the users of recycled water. Short-term evaluation of results. Corrective responses.

Notes: CCP=critical control point; CWW=City West Water; HACCP=hazard analysis and critical control points; QCP=quality control point; RWQMP=Recycled Water Quality Management Plan; RWTP=recycled water treatment plant; UF=ultrafiltration

4.12 Documentation and Recordkeeping

This step is relatively straightforward and doesn't need to be discussed in detail; however, the step was essential to provide evidence of operational compliance with the HACCP plan. In addition to this compliance role, records were also being used for trend analysis and continuous improvement. The types of documents and records kept included summaries of regulatory requirements, external certification requirements, any monitoring results, asset management plans, and emergency response plans (see Tables 4.23 and 4.24). Many utilities also documented communication and reporting requirements, such as monthly performance reports. Examples of the most important records directly referenced in the HACCP plans and likely to be subject to HACCP audit included:

- hazard analysis and risk registers
- recycled water quality monitoring results
- deviations from critical limits and corrective actions undertaken
- internal audit reports
- validation and verification records
- training records
- calibration records

Table 4.23. Documentation and Record Management—SA Water Glenelg–Adelaide Recycled Water Scheme, Recycled Water (Supply) Management Plan

Aspect	Procedures, Documentation, or Processes	Description
Preventative measures and their purpose	Equipment manuals	Supplier (in-built) controls and alarming
	Operations manual	Overall system controls and responses
	Control philosophy	Detailed system controls and responses
	SCADA alarm instructions	Operations-recommended responses to specific alarms
	Project risk assessments	Overall system risks and management responses
	Recycled Water (Supply) Management Plan	Overall management system for recycled water supply and application
Operational procedures	GRWTP operations, readings, and reports	Operational instructions for normal system operation
	GARWS: Operations Manual (GPA, 2009)	Overall system controls and responses
Operational monitoring protocols	GL-01 Daily Reporting and Readings	Daily collection and management of process monitoring data
	GL-04 Collection of On-site Samples	Collection of verification monitoring samples
	UW Laboratory Manual	Verification sampling and monitoring program
	T-01 Process Control—Monitoring	Review of SCADA system, trends, and routine monitoring data
Schedules and timelines	UW Laboratory Manual	Frequency of verification sampling and monitoring
	UW-01 Management Review	Frequency of management review forums
	UW-03 Document Management	Frequency of review of procedures and forms
Data and records management requirements	T-04 Control of Monthly Abstract	Recording and management of routine operational monitoring and verification data
	UW-03 Document Management	Procedures and timelines for the retention of data and records and review frequency for all procedures
	UW Intranet	Access to all current UW procedures and forms to facilitate version control
	UW-02 Performance Improvement	Management of internal and external audits and audit frequencies
Corrective actions to be implemented when required	Equipment manuals	Supplier-recommended responses to operating events
	Control philosophy	Detailed control instructions following operating events
	Operations manual	Design-recommended responses to operating events
	UW operating procedures	Operational responses to operating events

Table 4.23. Documentation and Record Management—SA Water Glenelg–Adelaide Recycled Water Scheme, Recycled Water (Supply) Management Plan *(continued)*

Aspect	Procedures, Documentation, or Processes	Description
	SCADA system	SCADA alarms and point instructions with response actions
	Emergency Response Plan	Specific correction actions for incidents and notification protocols
	UW-02 Performance Improvement	Procedure for monitoring the initiation implementation and closeout of corrective actions
Maintenance procedures	equipment manuals	Specific equipment maintenance requirements or actions
	maintenance plan	Recommended frequency of maintenance activities
	Maximo	Computerized maintenance management system for scheduling and monitoring maintenance activities
	Asset management plan	Annual review of equipment condition and performance
Responsibilities and authorities	SA Water Charter	Defines roles and responsibilities of SA Water
	Project Alliance Agreement	Defines scope of CityGreen Alliance in delivering GAP Recycled Water Project
	UW contract	Defines scope of UW activities in metropolitan Adelaide
	ACC Recycled Water Supply Agreement	Defines scope and responsibilities of Adelaide City Council
	UW-04 Compliance	Ensures compliance with contractual requirements, legislation, standards, and licenses
	UW-05 Contract Management	Ensures appropriate management of contracts and allocation of responsibilities
Training and awareness	UW WWT Induction Workbook	Induction process to provide awareness of site-specific risks to contractors and employees
	OPS-09 On-site Management of Contractors Health and Safety	Process for management of contractor activity on-site to ensure appropriate controls are in place
	QO96 Training Records	Training matrix and records for all employees
	Training manual	Corporate protocols for training of employees

Notes: ACC=Adelaide City Council; GARWS=Glenelg-Adelaide recycled water scheme; GRWTP=Glenelg recycled water treatment plant; SCADA=supervisory control and data acquisition; UW=United Water; WWT=wastewater treatment plant

Table 4.24. Documentation, Reporting, and Notification—City West Water Altona RWQMP and HACCP Plan

Documentation	Reporting	Notifications
CWW maintains records in relation to the ARWP. Documentation relating to the ARWP is managed within CWW's IMS, which can be located on the CWW intranet. The IMS includes detailed information on: * preventive measures * operational procedures, monitoring, and corrective actions * incident and emergency response plans * training programs * procedures for evaluating results and reporting * communication protocols	CWW will prepare an annual report for EPA and DOH on the ARWP, signed off by the general manager of Water Solutions. The report will include: * analysis of the monitoring data collected for the management of environmental risks * analysis of the monitoring data collected under the RWQMP * details of incidents and emergencies, including corrective actions * a statement of quality, quantity, and type of use of recycled water occurring in the ARWP * review in accordance with Section 13.2 of Guidelines for Environmental Management: Dual Pipe Water Recycling Schemes—Health and Environmental Risk Management, Publication 1015 * a statement of compliance with HEMP * a summary of audit outcomes * proposed measures for continual improvement	In the event of an emergency incident, CWW as the supplier and scheme manager must notify the appropriate regional office of EPA, any other relevant regulatory body, and affected parties as soon as is practicable. In the event of an emergency incident at the RWTP, Tedra Australia will notify CWW (operations manager) as soon as is practical. The Environmental Health Unit of DOH should be notified of the following: * a system failure that may potentially impact the end users of the recycled water * an emergency or incident that potentially places public health at risk * any changes to the RWQMP or operation of the treatment process that may adversely impact required microbial criteria Notification will be prompt and include details of current corrective and future preventative actions to be considered. The same event classifications and processes exist for recycled water as for potable water. CWW as the supplier and scheme manager will immediately notify all users (where applicable) of any incident that potentially places public health at risk. CWW has an existing contractual agreement with Tedra Australia to operate and maintain the RWTP. Tedra will notify CWW of any incidents that will potentially place public health at risk, and CWW will implement appropriate actions.

Notes: ARWP=Altona Recycled Water Plan; CWW=City West Water; DOH=Department of Health; EPA=Environmental Protection Agency; HEMP=health and environmental management plan; IMS=integrated management system; RWQMP=Recycled Water Quality Management Plan; RWTP=recycled water treatment plant

4.13 Prerequisite and Supporting Programs

In implementing the HACCP plan, it was important to identify other programs that may contribute to the safety and quality of recycled water supply (see Tables 4.25 and 4.26). Many of these programs are essential to safe outcomes but don't fit neatly into the HACCP 12-step process. These prerequisite or supporting programs provide information essential to the HACCP plan and can avoid duplication of work. Typical PRPs included things like:

- trade waste management
- incident response management
- treatment chemical QA
- asset management
- equipment calibration and maintenance
- staff training and awareness

Table 4.25. PRPs for Three HACCP Plans

Yarra Valley Water Aurora Recycled Water HACCP Plan	CWW Werribee Employment (Technology) Precinct Recycled Water HACCP Plan	South East Water Boneo RWQMP
Trade Waste Agreement and Sewage Quality Management System Emergency response plans Maintenance contractor's burst main, faulty meter, and hydrant repair procedures Maintenance contractor's main cleaning procedures Main cleaning work instructions Tank cleaning/operating works instructions Water main renewal program New main construction procedures Cross-contamination and personal disease Complaints Maintenance of pump stations Cathodic protection of tanks and pipes Maintenance contract audit procedures Pest control Treatment chemical QA Calibration and maintenance of monitoring equipment	Melbourne Water Western Treatment Plant CWW Incident and Crisis Management Plan Customer complaints Hygiene and sanitation, including equipment, staff hygiene, and work practices Vendor Assurance Program Nonconforming product and corrective action HACCP Verification Audit Program Calibration and maintenance of monitoring equipment Staff training/awareness PRP audit	Source Management System with a Sewage Quality Reference Manual certified under ISO 22000 to deal with trade waste management in the plant HACCP systems for QA and calibration of monitoring of instrumentation 5 year maintenance contract with the builders of the plant, which includes scheduled maintenance and calibration of process instrumentation All chemicals for the Class A plant purchased from Orica Chemicals, ISO 9001 certified and NSF accredited ISO 9000 certification, which provides an overarching organizational quality management system Training of staff by identifying the need, carrying out the training, and recording the details as required under ISO 9000

Notes: CWW=City West Water; HACCP=hazard analysis and critical control points; ISO=International Standards Organization; NSF=National Standards Foundation; QA=quality assurance

Table 4.26. PRPs—Melbourne Water Recycled Water Quality Management Plan

Program	Verification	Responsible Party
ISQMS	ISQMS certification	Sewage Quality Team
WTP civil assets renewals program	Capital Management System	Asset Management
Civil assets maintenance program	HANSEN system	WTP O&M Group
WTP M&E assets renewals program	Capital Management System	Asset Management
WTP M&E assets maintenance program	HANSEN system	WTP O&M Group
WTP site management and operations	Induction database, recipient training database, key logbook, OH&S management system	WTP O&M Group
SMIs	M&E audit program	WTP O&M Group
SOP	HACCP internal audit program operator training	WTP O&M Group
Operator Training Program	Skills matrix	WTP O&M Group
Approved chemicals register	ChemAlert system	WTP O&M Group
Sludge removal (including under anaerobic covers)	Desludging program	WTP O&M Group
Management of change programs	HACCP internal audit program	WTP O&M Group
Routine lab analysis	KPIs, chemical database	WTP O&M Group
Cleaning and sanitation hazards control programs	HACCP internal audit program	WTO O&M Group

Notes: HANSEN=proprietary asset management system; ISO=International Standards Organization; ISQMS=Integrated Sewage Quality Management System; KPI=key performance indicator; M&E-mechanical and electrical; OH&S=occupational health and safety; O&M=operations and maintenance; SMI=standard maintenance instructions; SOP=standard operating procedure; WTP=waste treatment plant

4.14 International HACCP Workshop

An International Peer Consensus Workshop on HACCP for Microbial Protection in Reclaimed Water Schemes was held in September 2010 in California over three days. The outline and recommendations from this workshop form part of this data analysis chapter and are summarized in Appendix A.

Chapter 5

HACCP and Supporting Programs: Gap Analysis

5.1 Rationale

The Utilization of HACCP Approach for Evaluating Integrity of Treatment Barriers for Reuse project builds on Australian and broader international experience with HACCP for recycled water management to evaluate, pilot test, and tailor a HACCP approach for microbial control in U.S. reclaimed water systems. Following an international workshop on HACCP, convened at OCWD (California) in September 2010 by the project team (refer to Appendix A), a need arose to conduct one or more gap analyses to compare existing recycled water facilities against HACCP requirements and supporting programs with respect to overall quality management, including but not limited to recycled water quality and microbial control. This chapter outlines two gap analyses that were subsequently undertaken by project staff in April 2011.

5.2 Abstract

Two recycled water utilities in Orange County, CA, participated in a gap analysis, or comparison, of their current quality management systems against the QA system known as HACCP. The gap analysis showed that although both utilities have mechanisms for controlling the safety and quality of their recycled water, their management systems display some fragmentation when compared to the more prescriptive and integrated HACCP approach. Nonetheless, the utilities' decentralized approach to quality management may offer some supplemental checks and balances as compared with the HACCP approach. The significance of these differences is discussed herein.

5.3 Background

HACCP is a QA system developed by NASA in the early 1960s to manage the risk of astronauts suffering food poisoning during missions. Since that time it has become globally recognized as the standard in food safety management. The United Nations has accepted the methodology, and its principles are evident in the Codex Alimentarius issued by WHO. In the late 1990s, some drinking water utilities in Europe and Australia became interested in applying HACCP to drinking water safety, and WHO incorporated HACCP principles in its subsequent WSPs.

In the last 5 or so years, some Australian utilities have extended HACCP to cover the supply chain in recycled water. This means applying the HACCP approach to source control, wastewater collection, STPs, advanced water reclamation plants, and even recycled water distribution and end use.

A further adaptation by some utilities has extended HACCP to cover the aesthetic aspects of drinking water, recycled water, and biosolids production.

5.4 Methodology

A checklist of quality system elements was prepared prior to undertaking the gap analysis. The checklist (Appendix B) contains elements taken from ISO 9000 and HACCP. ISO 9000 was included because HACCP requires certain support systems that are mandatory in ISO 9000 (Appendix C). The two systems often coexist. Indeed, the more recent international food safety standard ISO 22000 is designed for businesses that wish to combine ISO 9000 and HACCP in one system.

The checklist is generic; and, therefore, some items are not applicable to certain activities in each utility. The first utility studied was Irvine Ranch Water District (IRWD), which is responsible for source control, wastewater collection and treatment, water reclamation, recycled water storage and distribution, and recycled water service to customers. The IRWD Michelson Water Reclamation Plant (MWRP) is a conventional Title 22 water recycling plant. MWRP produces recycled water that is approved for nondrinking purposes under CC R Title 22 Water Recycling Criteria. MWRP features primary and secondary treatment, tertiary filtration, and disinfection processes. Recycled water is discharged to a distribution system, stored in reservoirs, and supplied to customers for approved uses, such as irrigation and toilet flushing.

The second utility studied was OCWD, which operates the Groundwater Replenishment System (GWRS), an indirect potable reuse project. Purified recycled water is used to supplement existing water supplies by recharging the groundwater basin and protecting it from degradation by seawater intrusion. The advanced water purification facility (AWPF) features microfiltration (MF), RO, advanced oxidation/disinfection consisting of hydrogen peroxide addition and ultraviolet light exposure (AOP/UV), decarbonation, and lime stabilization. Purified recycled water produced by the AWPF is injected at the Talbert Seawater Intrusion Barrier and recharged in spreading basins at the Anaheim Forebay.

The gap analysis investigators interviewed staff from various sections of each utility and conducted physical inspections of some production sites. Access to requested documentation was provided by both utilities. Because of time limitations and the high level approach of this gap analysis, some responses have been accepted without verification. Following the site visits, supplemental information was provided from each utility in response to questions related to this gap analysis.

5.5 Results

The findings presented here arise from the system elements of most interest in highlighting what differed between the pre-existing system and a possible HACCP approach. Each finding is prefaced with background information about the significance of the particular HACCP element.

An assessment matrix was created that gives a 1 to 5 score for each utility against the checklist, based on the criteria outlined in Table 5.1. Scores for each of the HACCP checklist elements (Appendix B) and supporting programs (Appendix C) were designated by the gap analysis investigators based on information provided during the site visits and meetings with utility staff. The main purpose of this matrix is to provide a quick reference alerting the reader to areas of interest discussed in the body of the report.

Table 5.1. Scoring Criteria Used To Complete the Assessment Matrices

Score	Criteria
1	No evidence of meeting this HACCP checklist item was observed.
2	There is evidence of this element in some parts of the utility, but implementation is generally incomplete in the processes examined.
3	There is evidence of this element in most or all parts of the utility, but implementation is often incomplete in the processes examined.
4	This element was complete in some processes within the utility.
5	This element was complete in all or most of the utility.
NC	Not confirmed
NA	Not applicable in this context

5.5.1 Commitment to Quality Systems

The benefit of an endorsed quality policy is that it provides a formal commitment to customers and a focal point for the efforts of production (and management) staff. The benefit of appointing a dedicated resource or staff person (even if added to an existing role) is that the overall integrity of the system is managed. Without a dedicated resource, QA naturally becomes fragmented as each part of the organization establishes order in its activities. In this case, fragmentation means that QC is decentralized, with each department or group responsible for its own quality system as it relates to the agency's overall quality policy. Under the HACCP approach, one individual within the organization is appointed by senior management and assigned responsibility and authority for the quality management system.

Related to resources under the HACCP approach is the requirement for the utility to have a well-defined organizational structure that can be perpetually audited for integrity. Such a structure means that, as individual staff members leave and management changes, the core of the utility's resource system is preserved and documented by a clear organizational chart. HACCP encourages utilities to develop succession plans to maintain quality.

5.5.1.1 Irvine Ranch Water District

There was clear evidence of a districtwide commitment to product quality and customer satisfaction at the highest levels of the utility. IRWD management has adopted formal mission and vision statements that support the values of the district, which include providing high quality, efficient, and cost-effective water and sewer service and emphasizing customer satisfaction as a primary objective. Further, there was evidence that this commitment is recognized by production and distribution staff. For example, in every IRWD meeting room there is a plaque entitled "Irvine Ranch Water District—Critical Business Factors." These factors were adopted and are updated as necessary by the IRWD Board of Directors. One of the factors listed is: "Quality—We must deliver potable and nonpotable water that meets all regulatory standards and customer requirements." The Critical Business Factors, including the district's commitment to quality, are provided to and discussed with each new IRWD employee and reinforced on an ongoing basis with existing staff.

Although there did not appear to be a specific resource dedicated to overseeing IRWD's QC system, it has indicated that every employee is held responsible for QC with the districtwide

Safety and Security Management (SSM) Department as a focal point. Each department provides input and receives guidance to manage risks and maintain safety and quality. Although fragmented, this decentralized approach effectively manages quality within each department by task and expertise. There is a job safety analysis for each position and piece of equipment that is available or required for the task. In addition to its facilities' O&M activities, IRWD operates its own water quality laboratory, which maintains a QA program.

IRWD has a well-defined organizational structure with positions described by job task. The interrelationships of each position are clearly shown and help establish responsibilities and communication procedures within the utility. As individuals leave or retire, the replacement resource fills that distinct role in the organization and is recognized in that position. Training programs develop junior staff to advance as they gain experience and ultimately fill senior positions.

5.5.1.2 Orange County Water District

OCWD is committed to water supply and reliability, water quality, environmental stewardship, sound financial management, and industry leadership and innovation. The actions and attitudes of staff interviewed at OCWD indicate that there is a very strong commitment to water quality throughout the organization. There is no formal quality policy; however, OCWD maintains a proactive water quality policy for the GWRS, monitoring (1) recycled water throughout the treatment plant and at recharge sites, (2) all other surface waters used for recharge, (3) groundwater throughout the basin, and (4) drinking water from production wells. Although the majority of the permit requirements focus on end-product testing, there are monitoring points throughout the entire treatment train, beginning with OCWD's partnership with Orange County Sanitation District(OCSD), which is responsible for source control, wastewater collection, and treatment, and continuing throughout the GWRS AWPF, upstream and downstream of each treatment process, and finally to the groundwater basin, tracking the recycled water, testing monitoring wells, and monitoring potable water wells. There did not appear to be any specific resource dedicated solely to running a formal organizational QC system. OCWD seems to favor a decentralized approach to quality management for more in-depth monitoring within each department with a system of checks and balances linking each group to ensure that QA assessments are performed and appropriate actions are taken to ensure compliance with pre-established quality criteria.

OCWD also has a well-defined organizational structure with specific job descriptions. The organization chart clearly illustrates the interrelationships of each position and helps establish responsibilities and communication procedures within the utility. As individuals leave or retire, the replacement resource fills that role in the organization and is recognized by others at that position. Training programs develop junior staff to advance as they gain experience and ultimately fill senior positions. OCWD recognizes the value of succession in maintaining integrity and quality.

5.5.2 Product Specifications

Product specifications in manufacturing are generally designed to consider customer satisfaction as well as any regulatory requirements. Indeed, a specification reflecting customer need is axiomatic for a business wishing to pursue customer satisfaction. This approach is less common in the municipal recycled water industry, in which the product specification is a permit issued and enforced by the state. The permit lists the product water quality numerical limits that must be met as well as the monitoring and reporting requirements. The adequacy of this approach will depend on the comprehensiveness of the permit or regulatory requirement.

5.5.2.1 Irvine Ranch Water District

At MWRP, the specification for the product, which is disinfected tertiary effluent recycled water, is based on the permit issued by Santa Ana Region RWQCB as Order No. R8-2007-0003 (National Pollutant Discharge Elimination System No. CA8000326). Permit limits are set forth based on CC R Title 22 Water Recycling Criteria and RWQCB Water Quality Control Plan (Basin Plan). IRWD operates MWRP and its recycled water system in accordance with this permit and also has internal specifications established by IRWD staff to optimize performance. For example, SOP is followed with constant monitoring by the SCADA system, in which instruments have set points with alarms to automatically signal alerts and trigger actions. In addition to meeting the product specifications, the district has implemented a comprehensive customer satisfaction program that ensures that customer inquiries are promptly addressed and follow-up actions initiated as necessary.

5.5.2.2 Orange County Water District

At GWRS, the specification for the product, which is advance-treated, purified, recycled water, is based on the permit issued by the RWQCB as Order No. R8-2004-0002 and amended by Order No. R8-2008-0058. At OCWD, there are internal specifications that production staff have set to drive process management. These internal specifications include CCPs and limits for operating the AWPF treatment processes and OCWD's policy to produce purified recycled water in compliance with drinking water notification levels even though such compliance is not required by the permit. These CDPH notification levels and Office of Environmental Health Hazard Assessment public health goals are not required by the permit but are product specification goals set by OCWD.

The permit lists product water quality numerical limits that must be met. For example, GWRS purified recycled water must meet drinking water standards. As such, the permit for this indirect potable reuse project is as stringent as potable water supplies delivered directly to consumers. The GWRS permit also requires that the purified recycled water produced for groundwater recharge comply with the RWQCB water quality objectives set forth in the Basin Plan. OCWD, as manager of the Orange County Groundwater Basin, serves groundwater producers who pump drinking water from the basin. These groundwater producers, which include cities and special districts such as IRWD in OCWD's service area, are effectively OCWD's customers. OCWD meets regularly with the groundwater producers and responds to their questions and concerns pertaining to local groundwater supply.

OCWD operates the GWRS using a sophisticated Emerson Delta V digital PCS. The operators can access, view, and control set points used to optimize operating conditions and maintain purified recycled water quality.

5.5.3 Document Control

Document control is the mainstay of quality systems such as HACCP. In practice, document control means that key documents (e.g., important procedures, policy documents) are given a version number, and all current official versions are located in one part of the company's computer system. A small number of employees (3–4 for the size of IRWD or OCWD) have write access to the system and only make alterations that are approved by a prescribed level of management (usually the relevant director or general manager).

The level of documentation varies from business to business and from utility to utility. Selecting the right level of documentation depends on the business or utility and its culture. Often workers need few procedures because they know how to perform their daily tasks. The hazard analysis part of HACCP (see the following) often assists businesses and utilities in determining the level of documentation required in the system.

From a diligence perspective, document control has the following advantages:

- It is a formal record that instruction exists.
- It assists employees in understanding obligations.
- It assists auditors in assessing the health of a QA system.

5.5.3.1 Irvine Ranch Water District

At IRWD, the SSM Department is responsible for maintaining documents related to safety and risk management. The SSM Department maintains all emergency procedures, materials safety data sheets (MSDS), and right-to-know labels for chemicals on the shared network drive, which is accessible to all employees. Updates to these documents are restricted to one person in the SSM Department. IRWD has a document retention policy that ensures that documents are reviewed periodically and current versions maintained in a central depository. Safety procedures are distributed to the various departments, and managers must acknowledge receipt of the documents in writing. Safety- and security-related documents are well-maintained and controlled.

IRWD maintains written documentation for each job, piece of equipment, and chemical receiving and handling operation. With regard to other operational procedures, the level of document control rests with each respective department. Process operating documents are stored in several locations and controlled by senior operations personnel. For example, only the operations manager can make changes to the MWRP SOP. In the near future, as part of the MWRP expansion project, IRWD expects to launch an electronic O&M system that will further enhance document control. A computerized maintenance management system (CMMS) is used for maintenance work orders, and a new enterprise asset management system is planned. These systems will be useful to the district's finance system, which is controlled by the finance department to track O&M budgets and procurements. Finally, IRWD operates a state-certified laboratory, which has comprehensive written procedures, records management, and document controls. All water quality data are recorded, checked, and maintained in the district's networked laboratory information management system (LIMS). The basis for a systematic approach to centralized management and version control of all documents appears to be in place at IRWD.

5.5.3.2 Orange County Water District

The OCWD Risk and Safety (RS) Department handles all emergency preparedness, safety procedures, and security issues. The RS Department maintains safety manuals and emergency plans, and one person is responsible for updating these documents. Updates are distributed in hard copy form to section chiefs for departmental files. Electronic copies of the latest documents are kept on the OCWD intranet and available to all staff. MSDS for chemicals are currently maintained as hard copies by departments using the chemicals; however, OCWD is upgrading the MSDS system to upload electronic documents on the OCWD intranet, allowing all departments to view them. The RS Department also tracks mandatory safety training by department and personnel.

There is no formal centralized organizational document control system at OCWD. For the most part, each department maintains its own document control system, but some documents are linked. For example, it was noted that the water treatment plant staff had their own document control system, which seemed to have the characteristics of a well-run formal system. The AWPF is operated using an electronic (online) O&M manual, which can be accessed by staff, but only designated senior personnel are authorized to make revisions. Similarly, OCWD uses a CMMS to track work orders and schedule predictive equipment maintenance for the AWPF. The CMMS is tied to the district's financial system, which tracks costs. OCWD's maintenance and GWRS operations departments maintain documentation on each repair job, including who performed the work, with specific equipment or vehicle tag numbers. These are entered electronically by department for maintenance staff to assign, schedule, and complete the work order. As noted in the GWRS annual report, a comprehensive list of maintenance activities is tracked, stored, and available for review and assessment.

OCWD operates a state-certified Advanced Water Quality Assurance Laboratory, which has strict written procedures, records management, and document controls. All water quality data are recorded, checked, and maintained in the district's networked LIMS and water resources management system (WRMS). Well records, groundwater levels, and production and recharge data are also maintained in WRMS. The LIMS and WRMS data management systems are highly developed and well controlled. Other examples of formal document control are evidenced in the finance department. Because of time constraints, a detailed review of the LIMS, WRMS, and financial system was not conducted. Although some elements may be decentralized, the various OCWD departments use this approach for QA by cross-checking information. Much formal document control already exists, with department managers and senior staff held responsible for maintaining records, procedures, and other documents. The basis for a systematic approach to centralized management and version control of all documents appears to be in place at OCWD. The water quality department has SOP for a wide range of tasks, such as collection of volatile organic compound and microbial samples, which may be specific by method or program (recycled water and stormwater), handling and processing of pumped groundwater, discharge requirements, and compliance activities (e.g., stormwater collection SOP, RWQCB de minimus permits).

5.5.4 Hazard Analysis

This is a key element in HACCP. For any given process, the steps are listed. Each step is subjected to a "what are the hazards and what can go wrong here?" analysis by a group of people familiar with the process. The hazards are listed, and those considered important by the group proceed to have monitoring, control, and corrective actions documented. This work is the heart of the HACCP plan, and because it is documented, it yields similar advantages to those of document control. The hazard analysis is usually only done once but may be updated by mechanisms such as annual management reviews, results of annual internal audits, and input from the continuous improvement system. Hazard analyses need not be restricted to production processes; the principles can apply to administration and distribution activities.

5.5.4.1 Irvine Ranch Water District

IRWD has had an independent security vulnerability assessment prepared that analyzes its infrastructure and process risks. It complies with hazard analysis and risk management programs on all levels, from federal Department of Homeland Security to state California Emergency Management Agency to local county and city agencies. Each job and piece of equipment has been evaluated for hazards related to production and distribution activities. An important example deals with chemical deliveries and handling in which hazards are identified and mitigated through outlining proper receiving and processing procedures. Often hazards have been considered at the design stage and mitigations included in the "as constructed" facilities. There was also evidence of process adjustments obviously designed to manage hazards and evidence of hazard identification and mitigation in the customer supply and distribution systems. Many of these are a result of the district conducting HAZOP analyses for specific processes and treatment facilities. The outcomes of these HAZOP studies are incorporated into the facilities design, and operational drills are conducted to train staff.

5.5.4.2 Orange County Water District

OCWD has analyzed risks associated with the GWRS since the early project planning stage. In 2000, the water quality evaluation prepared by Eisenberg, Olivieri, and Associates, Inc., compared the relative risk to human health with and without the project and provided information on the safety of the recommended treatment and use of recycled water for groundwater recharge. Hazards analysis of the GWRS is founded on the long-term, successful operation of Water Factory 21, a well-known predecessor that OCWD operated for three decades, supplying advanced treated recycled water to the Talbert Barrier.

The GWRS Operation, Maintenance, and Monitoring Plan (OMMP) identifies critical processes and emergency procedures, particularly for the AWPF and to some extent for the Barrier and spreading basins. Based on specific hazard analyses, OCWD has developed operating procedures for treatment equipment as well as chemical deliveries and handling. One person is responsible for bulk chemical deliveries at the AWPF. Two staff members are responsible for laboratory chemical deliveries and storage in the warehouse. OCWD and OCSD have developed joint SOP for operational activities involving staff from both agencies.

With regard to facilities, the same general observation made at IRWD applies at OCWD. There was evidence of hazard analysis being a significant influence in the design of the GWRS facilities as well as guiding certain behaviors in both AWPF staff and aquifer management practices. Although OCWD is exempt from DHS requirements because it is not a public drinking water utility, OCWD prepared its own vulnerability assessment to assess hazards associated with its facilities. OCWD complies with all Occupational Safety and Health Administration guidelines for equipment hazards and training for employee safety.

5.5.5 CCPs, Critical Limits, Monitoring, Control, and Corrective Action

The concept of CCPs is of interest to people investigating the use of HACCP. Unfortunately, the decision as to what constitutes a CCP is not always clear cut. Not only is there more than one method of determining criticality, it is possible to get different outcomes from the same method because of individual subjectivity. Generally though, a process step is considered critical if:

- Failure at that point is irreversible (e.g., disinfection).
- The step reduces risk to an acceptable level (e.g., denitrification).

For each CCP there will be some type of critical limit that the process step must meet (e.g., a disinfection chlorine CT or a nitrate concentration). The setting of these limits must be valid; they must be based on scientific data, a regulation, or have an empirical justification. In California, the Title 22 Water Recycling Criteria specify limits, many of which are in effect CCPs for processes (e.g., turbidity for filtration and coliform for disinfection).

It should not be inferred that noncritical process steps are neglected in the HACCP process. Indeed, many recycled water industry HACCP plans incorporate the multiple barrier approach in which lesser process steps are still optimized to reduce the burden downstream.

5.5.5.1 Irvine Ranch Water District

There is no doubt that in practice hazard analysis has, to a considerable extent, been carried out at IRWD. The MWRP operational staff are quite clear about their quality targets (the permit limits), and they have devised various methods of controlling quality (some of which are treated as critical). Similarly, the process of supplying and distributing recycled water is highly controlled. Staff has reviewed the areas that would be most adversely impacted by hazards and accordingly established emergency management plans. The MWRP multiple purpose room is designated as the emergency operations center in the event of an earthquake or other disaster.

In effect, IRWD has established CCPs for critical processes, which are monitored continuously with alarm set points requiring corrective action if the set points or critical limits are reached. IRWD facilities are operated using a computerized SCADA system with pagers and cell phones to provide 24-hour responses by operators, either by remotely logging into the operating system using laptops or physically going to the site.

5.5.5.2 Orange County Water District

Although not operating in a formal HACCP system, the recycled water production staff at OCWD runs the AWPF on HACCP principles. There was strong evidence documented in the OMMP that staff had determined process step criticality and identified internal critical trigger values beyond the final product specifications included in the permit. For these critical steps, monitoring and corrective actions are documented in the OMMP. The OMMP lists 12 CCPs with critical limits and corrective measures for the AWPF (Table 5.2).

Table 5.2. Critical Control Parameters at the AWPF at OCWD

CCP Parameter	Flow Stream or Process
Chlorine residual	MF feed
Chlorine residual	RO feed
Turbidity	MF feed
Turbidity	MF effluent
Turbidity	RO product
Transmembrane pressure	MF
Electrical conductivity	RO product
TOC	RO product
UV transmittance	AOP/UV
Average UV train power	AOP/UV
Calculated UV dose per train	AOP/UV
pH	purified recycled water

It was observed that AWPF staff tended to pursue optimal plant performance rather than merely compliance, and this is the hallmark of a strong QC culture. Further, the multiple barrier approach was used for the entire GWRS.

The AWPF control room is the primary point of contact for emergency events, including earthquakes or other natural disasters as well as chemical spills or similar issues. The AWPF control room is responsible for contacting local police and fire departments. Other emergency operations centers are the OCWD board room in Fountain Valley and field headquarters in Anaheim.

As noted in Section 5.5.2, OCWD has a PCS, or distributed control SCADA-like system, with similar continuous monitoring in the AWPF control room with alarm set points triggering corrective action if preset CCPs are reached. The AWPF control room is staffed 24 hours a day, and operators have cell phones enabling 24-hour coverage and response. Similarly, Barrier and Forebay operations staff may be called to respond after normal working hours, providing 24-hour coverage.

5.5.6 Verification—Internal Audit

Under HACCP, verification can be thought of in two ways:

- The product is in specification, meaning that the recycled water quality complies with the requirements.
- The elements of the QA system are functional (internal or external audit), providing review audits of the QA system itself.

The discussion in this section mostly relates to the audit aspects of verification. The process verification components attracted very high scores (they were considered to be done very well when set against a HACCP-type assessment) and so aren’t discussed further.

If a HACCP-type system is designed to maximize the efficacy of all process steps (critical and noncritical) and put in place valid operational targets, the need for end-product verification should be reduced. This approach is attractive to water utilities that (unlike food producers) do not have the luxury of product recall.

Verification of the QA system by audit is important. If audits are carried out by adequately skilled persons in the correct manner, they are a valuable mechanism for identifying system weaknesses before they become manifest.

5.5.6.1 Irvine Ranch Water District

At IRWD, end-product (recycled water quality) verification is comprehensive as required by permit. Online instruments are rigorously calibrated and checked by the mechanical and electrical services department, and calibration records are maintained for verification. The performance of MWRP treatment processes is periodically tested, optimized, and verified. Process monitoring was observed during the gap analysis. Recycled water quality is monitored at various points at MWRP and in IRWD's storage and distribution system. Diversion to the OCSD collection and treatment system is possible in the event of a major MWRP upset.

IRWD has no overall QA manager in the role of a dedicated resource that would be part of a HACCP approach performing verification by internal audit. Instead, internal audits are conducted in a decentralized manner in which one department cross-checks the outcomes of another department. External verification audits are conducted by RWQCB regulators in the form of review of monitoring reports submitted by IRWD in accordance with the permit and periodic onsite inspections.

5.5.6.2 Orange County Water District

As at IRWD, there is a large amount of end-product testing at OCWD, much of it driven by regulatory requirement. HACCP systems generally focus on optimizing production control to lessen the reliance on the lag indicator of end-product testing. Again, advanced process monitoring was in evidence at the GWRS AWPF. A considerable amount of recycled water testing is conducted at various steps through the AWPF to provide opportunities for process optimization and verification of treatment performance. Evidence of some verification auditing was found in annual reports prepared by an independent consultant and project reviews by an independent advisory panel, both of which are GWRS permit requirements. Although these appear to function as external audits, little evidence of formal internal audit was observed, primarily because of the lack of a designated resource or staff person to perform such a task. Instead, OCWD uses a decentralized internal audit process of checks and balances in which one department reviews the data, operating records, and performance of another department. As noted earlier, water quality data are reviewed as they pass from the LIMS (laboratory) system to the WRMS (water resources) database. In effect, this accomplishes a form of internal audit.

OCWD staff follows a rigorous calibration schedule to ensure proper calibration of the numerous instruments used to operate the AWPF and monitor purified recycled water quality. The O&M staff review water quality data to confirm process performance. OCWD's state-certified laboratory is audited biannually by the CDPH, covering all phases of laboratory operations, instrumentation, training, and QA programs. The laboratory must perform proficiency testing (PT) studies twice a year as part of the state certification process for compliance analytical services.

5.5.7 Emergency Preparedness

There is quite a variety of ways this element can be handled by a business or utility. The basic approach is to have a generic plan that allows anyone to declare an emergency or incident, which then triggers the assembly of an incident management team that then plans a response. At the other end of the scale are businesses or utilities that have specific contingency plans for various failure scenarios and run simulations of incidents. Normally, the hazard analysis will inform the level of preparedness required.

5.5.7.1 Irvine Ranch Water District

IRWD uses proactive planning for emergency preparedness. In an effort to be prepared for all emergencies, IRWD has emergency procedures in place. IRWD policies and procedures follow the National Incident Management System (NIMS) and Standardized Emergency Management System (SEMS) in accordance with the Federal Emergency Management Agency (FEMA) under DOHS. Each employee is provided with an IRWD emergency plan red binder (given during new hire safety orientation) as well as an updated emergency employee directory. Various levels of staff are trained in emergency operations of the district and FEMA certified in IS-NIMS (Independent Study) in accordance with 2003 Homeland Security Presidential Directive 5.

IRWD is a participating member in Water Emergency Response Orange County (WEROC), which serves the County Operational Area water services liaison during an emergency event. IRWD has dedicated resources that participate in scheduled exercises throughout the year to promote planning and preparedness activities to support effective emergency response.

IRWD has various emergency response communication channels. IRWD CodeRed Emergency network allows customers to receive messages by voice, email, or text giving specific emergency details and what to expect. In some cases, customers may be visited door-to-door by an IRWD employee who will provide necessary information. The district has a 24-hour emergency hotline (949-453-5300); during an emergency, customers will be able to speak with a customer service representative or listen to a recorded message. IRWD also uses social media for updates with its IRWDemergency Twitter channel and Situation Status Updates on the IRWD Facebook page and news bureau.

IRWD maintains a Technician Level Hazardous Materials Response Team (HAZMAT). The HAZMAT team is trained and fully equipped to handle hazardous spill containment and cleanup. Risk management procedures are used to maintain the mechanical integrity of all chemical storage and feed systems at MWRP.

The district has contingency plans for major process failure at MWRP and long-term recycled water quality problems (e.g., blue-green algal event or release of un-disinfected recycled water). Utilization of other water sources, including raw, untreated water or potable water to supply the recycled water system, would keep SOP in place and maintain service to customers. IRWD can divert raw wastewater to OCSD for treatment until MWRP is back online.

5.5.7.2 Orange County Water District

OCWD also uses proactive planning for emergency preparedness and has procedures in place in an effort to be prepared for all emergencies. OCWD policies and procedures follow NIMS and SEMS in accordance with FEMA under DOHS. Each section chief is provided with a hard copy of the OCWD emergency preparedness plan, and electronic copies are available to all staff on the OCWD intranet. Various levels of staff are trained in emergency operations and FEMA certified in IS-NIMS in accordance with 2003 Homeland Security Presidential Directive 5. Refresher training and participation in simulated exercises are mandatory.

OCWD is a founding member and one of the funding agencies for WEROC and has dedicated staff to promote training for planning and preparedness activities to support effective emergency response to a major disaster in the Southern California region. OCWD participates in scheduled training and table-top exercises to prepare for emergencies in the region.

OCWD maintains an Incident Command Center in accordance with FEMA guidelines for emergencies such as earthquakes and chemical spills. OCWD has various emergency response communication channels. Local neighbors may be visited door-to-door by OCWD staff who can provide necessary information. The AWPF Control Room is staffed 24 hours a day as an emergency operations center. In addition to cell phones, OCWD staff use hand-held and long-range radios to communicate with their three base stations at the AWPF, Forebay Field Headquarters, and Prado Operations centers. OCWD is also active in social media, utilizing Facebook, LinkedIn, and Twitter.

OCWD maintains a Technician Level HAZMAT Response Team that is trained and fully equipped to contain hazardous material spills and cleanup. As noted earlier, OCWD manages risks associated with all chemical storage and feed systems at GWRS. The HAZMAT team training and response includes full protective gear and simulated exercises and refresher courses scheduled by the RS department.

The GWRS provides peak wet weather flow relief for the OCSD ocean outfall. OCSD's Reclamation Plant No. 1 supplies treated secondary effluent as source water to OCWD's GWRS. The two agencies have joint SOP for peak wet weather flow conditions. Other joint SOP for shared operating conditions are contained in the OMMP. Because it is not imperative that the GWRS operate at all times, OCWD can shut down purified recycled water production if necessary. For long-term outages, OCWD can supply the Barrier with potable water and recharge purchased imported water or Santa Ana River water at the spreading basins.

5.5.8 Control of Raw Material

This element is extremely important to food suppliers who routinely access ingredients from other producers or growers. Usually the food producers require suppliers to provide some sort of batch test certificate as well as employ HACCP or some other formal QA system. HACCP-certified water utilities usually only buy chemicals from ISO 9000 certified suppliers that can provide batch testing certificates for each delivery. When HACCP is applied to a WWTP, however, a complication arises. The major ingredient is the raw sewage provided by residents and businesses of the surrounding catchment, and QC is extremely difficult.

In Australia in recent years, HACCP principles have been applied by some sewage collection agencies in an endeavor to better manage risks to receiving treatment plants and their end products (recycled water and biosolids). Although not able to eliminate all risks, this approach helps focus resources on the highest risk sources.

5.5.8.1 Irvine Ranch Water District

At IRWD, control of quality from chemical and material suppliers appears to be well managed. IRWD has control procedures and plans in place that enable staff to purchase chemicals and materials from new suppliers should a problem be found. The district has backup suppliers for chemicals so that supplies are not interrupted.

With respect to wastewater quality, IRWD follows the same Pretreatment and Source Control Program as OCSD. Besides complying with federal and state industrial pretreatment standards, OCSD provides enhanced source control to support water recycling (discussed in a later section). Time did not allow investigation of the sophistication of feedback loops between IRWD and OCSD.

5.5.8.2 Orange County Water District

OCWD and OCSD have a joint operating agreement that supports the GWRS permit requirement for enhanced source control to prevent contaminants from entering the wastewater tributary to Plant No. 1, which may be harmful to the treatment facilities, environment, or human health and drinking water supplies. Through an expanded monitoring program, OCSD can reduce the likelihood that the secondary effluent delivered to the AWPF is contaminated with toxic chemicals of industrial origin that are of concern for public health. This program protects the GWRS purified recycled water quality. On a previous visit, source control staff at OCSD were interviewed, and there is no doubt that such staff realize and take seriously their role in reducing risk to Plant No. 1 and the OCWD AWPF. Time did not permit an inspection of the wastewater QC system at Plant No. 1.

OCWD water production staff manage the quality of the chemicals used in the AWPF. SOP is followed to control chemical quality. OCWD uses National Standards Foundation (NSF) drinking water–grade chemicals at the GWRS to ensure that the purified recycled water is safe for recharge to the groundwater basin, which is a source of drinking water, and that the chemicals have been through a strict QC process during manufacturing. Each chemical delivery manifest is checked upon delivery to ensure that it meets the minimum purity requirements specified in OCWD’s contract with the chemical supplier. As at IRWD, replacement suppliers can be substituted if material quality is questioned. Should problems or issues arise from use of a chemical in the AWPF treatment processes, OCWD coordinates closely with chemical vendors to initiate special testing of products to address issues or provide higher quality materials for use in the process.

5.6 Conclusions

As indicated in Appendices D and E, the utilities scored well on most checklist items. There were examples of outstanding performance and examples in which opportunity for improvement exists in terms of the HACCP approach.

As things stand, there is quite a strong reliance on key people and the verbal transfer of knowledge in both organizations, even though both utilities have well-defined organizational structures with succession plans. Furthermore, the use of formal documentation, risk assessment, and continuous improvement systems is unevenly applied, varying from department to department.

The performance of both utilities inspected is mainly measured in terms of their compliance with state permits. It seems doubtful that having HACCP plans would reduce the amount of end-product (recycled water) monitoring required under their permits. Because their levels of compliance are high, it can be inferred that current risk management and QC practices are adequate. Additional monitoring of recycled water quality is conducted to optimize treatment process performance and ensure that the product is safe. Both utilities also measure performance in terms of customer satisfaction.

Furthermore, it is not necessarily the case that introducing HACCP would provide an appreciable benefit to either utility. Although HACCP is an alternative approach to quality management, it is not necessarily the only successful approach. In other words, it is possible to use a HACCP plan to preserve modest performance while providing the impression of high performance, transparency, and accountability. Both of the utilities in the gap analysis achieve consistently high performance, transparency, and accountability without HACCP plans.

On the other hand, a well-designed and implemented HACCP plan may offer several advantages, further enhancing the quality management systems in place at both utilities, including:

- Centralized QC under HACCP helps focus the purpose of staff while providing executives with an efficient portal into staff front-line, on-the-ground activities. Although QC is not lacking, the utilities' QC systems use a decentralized approach of checks and balances rather than a centralized approach.
- Formal hazard analysis, monitoring, control, and corrective action with defined roles and responsibilities clarify what is expected of staff while providing evidence of managerial and organizational diligence. It is recognized, however, that both utilities have formal job descriptions and organizational charts. Staff clearly understand and are held accountable for assigned duties. In practicality, sometimes staff members wear many hats in order to accomplish tasks. HACCP would increase formality and reduce overlaps, but may not necessarily improve overall workplace efficiency.
- Suppliers and customers benefit from and appreciate dealing with a utility in which commitment is formalized and product quality is optimized, consistent, and transparent. Under HACCP, these commitments would be formally documented and audited. Both utilities have Boards of Directors that adopt formal policies and agreements for dealing with suppliers, customers, and other agencies. Both utilities are required by state law to be transparent for public scrutiny and achieve required product (recycled water) quality.
- HACCP encourages the use of feedback systems throughout all levels of the organization to facilitate continuous improvement. Regulatory audits of the utilities' records and inspections are periodically conducted by the state. HACCP would add formal internal audits for additional in-house QC and reinforce informal department-to-department feedback systems.
- A technically competent auditor can efficiently provide insight into the health of any part of a utility run along ISO 9000/HACCP principles. NSF International certifies HACCP plans and conducts audits.

Given the insights from the assessment, sufficient understanding was gained to enable completion of the project objectives without necessitating a full HACCP implementation pilot component of this project.

Chapter 6

HACCP Plan Templates

6.1 Background

The original project scope included conducting at least two U.S. HACCP pilots. This was subsequently amended to the preparation of three HACCP plan templates that covered a range of reclaimed water systems, including advanced treated reclaimed water (for indirect potable reuse), disinfected tertiary reclaimed water, and disinfected secondary reclaimed water.

The main reason for the scope change was the gap analysis activity, a scope addition to the project that arose from the international HACCP workshop. The gap analysis study (refer to Chapter 5) was in effect the completion of two high level HACCP audits at OCWD and IRWD, and these studies went a long way toward demonstrating the expectations of a HACCP approach for two working plants. Perhaps the need for a change in scope was best summarized by OCWD, when it indicated in regards to a U.S. HACCP pilot:

> there doesn't appear to be sufficient value in essentially re-packaging much of the information already contained within the Gap Audit document and our pre-existing Operations, Maintenance, and Monitoring Plan (OMMP).

This sentiment was endorsed by the project team and subsequently approved by the WateReuse Research Foundation after assessment by the Project Advisory Committee.

6.2 Generic HACCP Plan Templates

The project team has prepared three HACCP plan template documents that may be used by any utility as a guide towards implementing its own HACCP system. The three HACCP templates cover the bulk of the different reclaimed water qualities that are currently produced, including:

- advanced treated reclaimed water (for indirect potable reuse)
- disinfected tertiary reclaimed water
- disinfected secondary reclaimed water

The HACCP plan templates are included in Appendices F through H. These documents are also available as separate word files.

6.3 Developing HACCP Plans for Specific Situations

At first sight, it may appear that all that needs to be done to complete a HACCP plan is to copy and slightly adapt the template—a task that could perhaps be done by one person working in an office in virtual isolation. That is not the case. It is essential that the template documents be used as no more than that. Each recycled water supply system will have its own hazards, risks, and process controls. Even for essentially very similar recycled water schemes, the finer details of the process controls can be very different.

HACCP requires precision and justification in relation to the principal hazards that need to be controlled as well as the process control limits (critical limits) that need to be achieved in order to demonstrate control of those hazards. Those process control limits need to be validated specifically for each system. Therefore, a HACCP plan, even if based on a template for a very similar recycled water scheme elsewhere, will need to complete the following steps:

- Assemble a team that includes those with knowledge of the specific system.
- Construct a process flow diagram for the specific system.
- Identify the specific intended uses and users of the recycled water.
- Undertake a risk assessment workshop to identify scheme-specific hazards.
- Complete the detailed description of the process controls, including designating CCPs, identifying critical limits, establishing operational monitoring of the critical limits, and developing corrective action plans, all for the specific recycled water scheme.
- Validate the technical veracity of the assumptions used in the risk assessment and the capability of the CCPs when operating within their critical limits for the specific context.
- Develop and implement the range of supporting programs for the specific context.

Clearly, if starting from a less formal, less automated, initial position, the implementation of HACCP as currently interpreted involves significant work for multiple staff to move to something equivalent to a full HACCP system. On the other hand, for existing, well-managed, -automated, -monitored, and -regulated recycled water schemes, the retrospective application of HACCP is sometimes a relatively modest exercise. In many situations, most of the requirements of HACCP, or at least their intent, are addressed through the application of established approaches to design, construction, operation, and regulation of recycled water schemes. A key conclusion from the gap analysis for the two recycled water schemes examined was that, although there may be areas where activities were not identified using the same jargon as that found in HACCP, the intent of HACCP had largely already been met. Therefore, a useful due diligence process for a recycled water scheme can be the completion of a HACCP study that essentially looks for gaps between what is in place and what would be in place were HACCP implemented, and then considers filling any gaps. Renaming may or may not be useful if, for instance, process controls are not termed CCPs or contaminants are not termed hazards.

6.4 Common Areas of Weakness Where HACCP Has Not Been Applied

Gap analyses conducted for a number of jurisdictions over many years by the authors of this report have noted that the following are the most common failings that exist in situations in which HACCP has not been applied but that would be solved through the use of a good HACCP system:

- Risk assessment for health-related product quality. In many cases, existing schemes have been designed based on assuring the achievement of final water quality criteria, often based on experience designing other schemes. Traditionally within the water industry, designers create schemes largely on the basis of tried and tested approaches. Any risk assessment that takes place is often of a more general engineering and personal safety nature, not a detailed and explicit health-related product quality risk assessment. Where HACCP is involved, it is necessary to single out health-related contaminants of concern (i.e., hazards in the

HACCP jargon) and then separately and systematically analyze the events by which such contamination might arise. This more in-depth, health-related product quality risk assessment can identify otherwise unforeseen risks.

- Validation and formalization of process control limits. In many cases, the reason for setting process control limits at process steps is not evident or based on first principles but founded on historical experience and the use of professional judgments made in the past and often embedded in rules of thumb. In addition, operators are able to exercise some discretion in adjusting process control limits, provided the final water quality results from the end-product verification testing program don't detect problems. In contrast, under HACCP the process control limits must be defined as the critical limits, are not subject to change at operator discretion, and must be justified based on objective evidence as part of the HACCP validation process. Furthermore, under HACCP, recycled water would essentially not be supplied if critical limits were not met until the process was operating back within its critical limits In situations in which HACCP has not been applied, the process control limits might be exceeded, and recycled water might go on being supplied while efforts were made to fix the problem.
- Formalization in general. HACCP is a management system that brings with it associated internal and external auditing and formalization of key processes. Traditionally, the water sector is somewhat averse to the use of formalized, documented, audited management systems and regulates itself largely based on end-product quality monitoring results. Where HACCP has been formally introduced, the discipline of committing processes to documentary form (whether that be on paper or in electronic media) and having conformity with the documented processes externally (lower frequency) and internally (higher frequency) audited, brings potential benefits in terms of overall reduction in risks of end-product nonconformity or harm to users.

Chapter 7

Conclusions and Recommendations

7.1 Background

The focus of this project was to build on Australian and broader international experience with HACCP for recycled water management and help evaluate and tailor a HACCP approach for microbial control in U.S. reclaimed water systems, including consideration of the benefits and disadvantages of adopting a HACCP approach. Although water reclamation in the United States is regulated by individual states, templates for three types of reclaimed water systems based on HACCP principles have been proposed for consideration by U.S. states for incorporation into their respective water recycling regulations.

7.2 Benefits of Adopting a HACCP Approach

HACCP can be usefully applied to urban water systems for both potable water supply and water reclamation, recycling, and reuse. HACCP is most readily applicable to treatment processes and less easily applied to source control, distribution system management, or point of use/user control.

HACCP is typically applied as one part of a broader management framework. Using HACCP efficiently and effectively for the control of microbial hazards within U.S. water reuse schemes would require its integration into existing management frameworks. It could be used to fill any gaps within or strengthen those frameworks.

Because water reuse is regulated by the states, it is probable that a state-by-state assessment would be warranted, building from a national guidance document. This project can build that national guidance and provide tools to help states and utilities implement HACCP for their reuse schemes to add value to their existing microbial control processes.

7.3 Implementation Challenges—Generic

There were several generic challenges identified for HACCP application outside of the food industry, for which it was originally designed and has been widely adopted.

The principal limitation has been more about acceptance than technical aspects. A negative reaction is often triggered when attempting to apply the HACCP approach to water treatment because professionals are put off by the common use of words that are clearly specific to the production of food. Most HACCP training courses and texts discuss identifying food safety hazards or the vital importance of adopting good manufacturing practice, which has a clear definition in food but is not a familiar phrase in the water sector.

For WHO, this food sector connotation led to the use of the WSP in preference to HACCP. Because HACCP is a food sector term and necessarily implies an international standard of product safety, it was considered by those working on the WSP document for WHO that the term WSP would be better suited to the water sector than the term HACCP.

A practical limitation comes from the issues associated with introducing a new set of concepts and terminology to an industry that may be new to people and not always intuitively meaningful. For example, what is the difference under HACCP terminology between validation and verification, and what is a CCP? Additional confusion may arise when several terms are in common use that are intended to mean the same thing, even within the food sector. For example, how are PRPs different from supporting programs, or are they in fact synonymous? This point is discussed in detail in Chapter 2.

In the past there were major technical limitations, but these have largely been overcome in the last 20 years. Several technical issues were highlighted approximately 20 years ago by Bryan (1993). The focus of these comments was on the state of automation and formalization in the water industry at that time. Bryan (1993) cautioned that the use of HACCP for the water industry was limited for a number of reasons:

- The structure, equipment, and cleaning standards applied in the water industry may be inappropriate (it is not typically of a food production facility standard).
- Effective communication may be lacking, preventing swift action when a problem occurs (many of the processes typically do not take place in an enclosed, controlled factory setting, and smaller utilities tend to lack reliable SCADA systems to detect and divert water that is out of specifications). This comment was made in 1993; the issue is becoming less significant as the water industry modernizes.
- The appropriate corrective actions may not be clearly documented (the sector is typically quite informal and has relatively little documented procedures). Once again, since 1993 that has changed and continues to change).
- The causative agent of waterborne disease outbreaks cannot always be isolated from either the water supply or the human case because of the lack of analytical methods for many pathogenic viruses and other microorganisms associated with drinking water samples (although the same could be said for food and bottled water, where HACCP is applied). Most existing analytical methods do not utilize online technologies, preventing an instantaneous reaction to failure. This can be addressed by monitoring physical parameters to control critical points (e.g., monitor particle counts to assess the possible presence of *Cryptosporidium* oocysts).
- If HACCP is applied only to treatment facilities and not the distribution system, it may not prevent a waterborne disease outbreak caused by distribution system inadequacies. (HACCP could of course be applied to distribution systems; see, for example, Martel et al., 2006).

Many of the limitations identified by Bryan (1993) have been increasingly resolved, and for many large potable and recycled water schemes these issues no longer apply.

The major adaptation in applying HACCP to the water sector as distinct from a typical food process is the continuity of the essential supply to consumers. Unlike an idealized manufacturing process, the provision of water often needs to be continuous, and the supply cannot always be batched, tested, and shut down for any extended period of time if problems are detected. Furthermore, shutting down a water supply is rarely an option because water supplies need to be maintained for firefighting, sanitation, and other general uses. This makes the monitoring and corrective action procedures more difficult to apply, particularly where there is no alternative water source available. In practice, the same is often true or partly true for food, however, and sometimes recalls need to be issued after food has been supplied to the market. Furthermore, the boil water advisory (or equivalent) is similar to a product recall or advisory to avoid consumption of certain foods.

7.4 Implementation Challenges Specific to the United States

In addition to the generic implementation challenges listed previously, several additional facts emerged from the project that may preclude the widespread adoption of a HACCP approach in the water sector.

Perhaps most significant is the notable difference in regulatory structure of the United States compared with some countries where HACCP has been widely adopted. For example, Australia adopts a risk-based approach to water treatment, whereby utilities must demonstrate to regulators that they have adequately considered and addressed the risks associated in complying with the ADWG or AGWR. Such a risk-based approach enables flexibility in approach to comply with the relevant guidelines, facilitating adoption of alternative approaches such as HACCP.

In contrast, the more prescriptive (regulated) approach adopted in the United States does not provide the same degree of flexibility in achieving the desired water quality outcome. For example, in theory the adoption of a HACCP approach should reduce the need for compliance monitoring; however, in the current regulatory environment, this may not be easily achieved. A significant concern expressed at one point during the project by a key stakeholder was that U.S. regulators may insist on a HACCP approach in addition to the current requirements, which would lead to additional cost, duplication of effort, and further inefficiency in the water treatment process. This might be the major concern for small to mid-sized utilities. The validity of that concern was not tested by discussion with regulators, but the perception remains strong in the meantime.

7.5 HACCP Is Not the Only Approach

It is important to emphasize that, although adopting a HACCP approach is considered a very good framework for risk management and control in water treatment systems, there are many other systems that achieve the same or similar outcome. Many well-functioning U.S. treatment plants have invested considerable effort to implement their own systems that address many of the issues covered as part of a HACCP approach.

This was highlighted during the gap analysis study (refer to Chapter 5) in which two very well-run water treatment plants were examined.

7.6 Recommendations

The gap analysis established that there are significant differences between the reuse water quality regulatory structures operating in the United States as compared to some other jurisdictions. The U.S. approach is currently more prescriptive and end product–driven than the regulations for Australia, Singapore, and some other jurisdictions that use an approach more like HACCP, even a literal HACCP approach in some cases.

The underlying objective of introducing HACCP to water reuse in these international jurisdictions was to achieve and assure continuous and reliable end–product water quality through process management to overcome the perception of fundamental limitations of a management regime focused primarily on occasional end-product monitoring.

It is perceived that introducing a HACCP approach to U.S. utilities that have an established treatment facility may not offer appreciable benefits because the end-product water quality outcome is so heavily prescribed by the permit issued to each treatment facility by a state regulatory agency. Based on the gap analysis, U.S. utility management may believe that HACCP would impose additional regulations, potentially increase costs, and duplicate efforts to achieve the same end-product water quality. The stringent U.S. regulatory requirements for transparency and end-product quality may hinder implementation of the entire HACCP approach, including reporting of process performance deviations and pass/fail certification audits, for most utilities.

On the other hand, U.S. utilities that are developing or changing a treatment process may find HACCP beneficial. Utilities in the planning or design phase of a new treatment facility or an upgrade to an existing treatment plant may benefit from the risk assessment tools provided by a HACCP approach, possibly enhancing product quality management. Using the HACCP process to support design and operational aspects of process monitoring and control would be useful to help reduce reliance on end-product testing. Furthermore, even where existing and very stringent regulations are in place relating to end-product quality, the discipline that the core of the HACCP approach brings to in-process rather than end-product monitoring has the potential to increase the reliability of the targeted end-product quality. HACCP templates are available as a guide for U.S. utilities.

It is important to acknowledge that the application of HACCP to recycled water supply systems cannot detract from the reliability of those systems that provide recycled water fit for the intended use. The key question, therefore, is whether the benefits of implementing a HACCP study, or even implementing a full, potentially certified HACCP system, outweigh the costs. Such an assessment can be made on a case-by-case basis through the exercise of professional judgment. It is noted that many international water utilities have used HACCP to assist in creating new recycled water schemes and enhancing existing ones even without a regulatory push to do so. Furthermore, the HACCP principles are all reasonable actions to complete. It is, therefore, reasonable to recommend HACCP as a good practice, product quality management tool and provide a summary recommendation from this project as follows:

HACCP has been demonstrated to be a useful, good practice, product quality management system tool. The study authors recommend review of and adherence to the intent of the HACCP principles by recycled water scheme operators and managers. Just how literal and formal an implementation of HACCP should be depends on the specific circumstances of each jurisdiction and scheme and can be judged on a case-by-case basis. Considerations include the current regulatory context, stage of scheme development, scale of scheme and utility, and quality of existing management systems. A minimum scale for the application of HACCP would be that which entails the provision of recycled water collected on one site for delivery and use at another site as distinct from a single on-site collection and recycling system.

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Appendix A

International HACCP Workshop

1.1 Outline

An International Peer Consensus Workshop on HACCP for Microbial Protection in Reclaimed Water Schemes was held in California over three days, as follows:

- Day 1. International experiences of applying HACCP to microbial control in reclaimed water schemes. Presenters from international water utilities were asked to talk frankly and openly about their experiences with HACCP and HACCP-like systems for microbial QC in water reuse.
- Day 2. Workshop on realizing the benefits while avoiding the pitfalls of applying HACCP principles to microbial control in reclaimed water schemes in the United States. A facilitated workshop systematically worked through and addressed questions such as the following:
  - Common themes emerging in broader aspects, such as:
    - What are the human resources time implications?
    - What are the financial and other tangible costs?
    - What are the financial and other tangible benefits?
    - What are the intangible benefits?
    - What's missing from HACCP that should be added into broader frameworks, if anything?
    - What's in HACCP that isn't required, if anything?
    - What are the experiences of HACCP steps and principles being integrated into broader frameworks?
    - What benefits arise for microbial QC versus other approaches?
    - What benefits arise for other types of QC (e.g., chemical risks)?
    - What are the implications and pros and cons of HACCP in regulation?
    - What are the tips for smooth implementation?
    - What are the barriers to implementation?
    - What are the reuse customer perspectives of HACCP?
    - How does the use of HACCP benefit public acceptance of and support for water recycling?
    - What is the ease of use of HACCP jargon and terminology?
  - Common themes emerging in technical aspects, such as:
    - hazards identified
    - risks identified
    - controls recommended
    - CCPs designated
    - process monitoring approaches
    - critical and alert limits
    - corrective actions
    - supporting programs and PRPs
    - other technical aspects

- Day 3. Finalize the plans for the pilot-scale studies for the U.S. water supply facilities in light of the previous days' findings.

Key representatives of the participating utilities from the United States, Australia, and Singapore were funded to attend the workshop from the project budget. Additional international and U.S. utilities were invited to self-fund and attend the workshop at the discretion of the PAC.

1.2 Workshop Agenda

Day 1: Wednesday, September 1, 2010

Arrival and tea/coffee in the lobby or kitchen area		**10:00–10:30**
1.	Welcome to OCWD (Mike Wehner)	10:30–10:40
2.	Background—Overview of project from WQRA (David Halliwell)	10:40–10:50
3.	From Rocket Science to Reuse Safety—overview and brief history of HACCP (Dan Deere)	10:50–11:00
3.	International experiences of applying HACCP to microbial control in reclaimed water schemes • Irrigation and low exposure schemes—Melbourne Water Werribee Irrigation District (Judy Blackbeard) • Dual reticulation and high exposure schemes—SA Water Mawson Lakes (Grant Lewis) or Gold Coast Pimpama-Coomera (Shannon McBride) - Potable reuse schemes—Singapore PUB NEWater (Mark Wong)	11:00–12:30
4.	Microbial control without HACCP - Overview of OCWD GWRS (Mike Wehner)	12:30–1:00
Lunch		**1:00–2:00**
5.	Study tour of the GWRS	2:00–6:00
6.	Close of day 1	

Day 2: Thursday, September 2, 2010

Arrival and tea/coffee in the lobby or kitchen area		**8:30–9:00**
1.	Detailed overview of project objectives and proposed deliverables (David Halliwell)	9:00–9:30
2.	Theoretical basis of microbial risk and how HACCP mitigates risk (Joan Rose and Mark Weir)	9:30–10:00
3.	Validation as a key principle of HACCP (Greg Leslie)	10:00–10:30
Morning break		**10:30–11:00**
4.	Facilitated discussion, part 1: Peer consensus on what is known about broader aspects of HACCP: - What are the human resources time implications? - What are the financial and other tangible costs? - What are the financial and other tangible benefits? - What are the intangible benefits? - What's missing from HACCP that should be added into broader frameworks, if anything? - What's in HACCP that isn't required, if anything? - What are the experiences of HACCP steps and principles being integrated into broader frameworks? - What benefits arise for microbial QC versus other approaches? - What benefits arise for other types of QC (e.g., chemical risks)? - What are the implications and pros and cons of HACCP in regulation? - What are the tips for smooth implementation? - What are the barriers to implementation? - What are the reuse customer perspectives of HACCP? - How does the use of HACCP benefit public acceptance of and support for water recycling? - What is the ease of use of HACCP jargon and terminology? Utility partners to provide advice based on their experiences with HACCP. (Debra Burris and Dan Deere to cofacilitate and capture the outcomes)	11:00–1:00
Lunch		*1:00–2:00*
5.	Facilitated discussion, part 2: Peer consensus on what is known about technical aspects of HACCP: • hazards identified • risks identified • controls recommended • CCPs designated • process monitoring approaches • critical and alert limits • corrective actions • supporting programs and PRPs • other technical aspects	2:00–3:30

Afternoon break		**3:30–4:00**
5.	Facilitated discussion, part 3: Beneficial application of HACCP to reuse in the United States	4:00–5:00
6.	Close of day 2	

Day 3: Friday, September 3, 2010

Arrival and tea/coffee in the lobby or kitchen area		**8:30–9:00**
1.	Summary of what emerged from Days 1 and 2 and implications for the project (Debra Burris and Dan Deere)	9:00–9:15
2.	Overview of trial sites for OCWD pilot of HACCP and discussion of its application (Mike Wehner)	9:15–9:45
3.	Overview of trial sites for WBMWD pilot of HACCP and discussion of its application (Uzi Daniel)	9:45–10:30
Morning break		**10:30–11:00**

4.	Facilitated discussion, part 1: How to complete and document the pilots for the preliminary steps and PRPs:
	- PRPs
	    o calibration
	    o maintenance
	    o training
	    o operating procedures
	    o traceability
	    o vendor assurance
	    o etc.
	- HACCP team
	- intended use and users
	- system description and flow diagram
	Utility partners to provide advice based on their experiences with HACCP. (Debra Burris and Dan Deere to cofacilitate and capture the outcomes)
		11:00–1:00

Lunch		**1:00–2:00**
5.	Facilitated discussion, part 2: How to complete and document the pilots for the HACCP principles: - hazard analysis - CCPs - monitoring - corrective actions - verification and validation - documentation and recordkeeping	2:00–3:00
6.	Facilitated discussion part 3: Finalization of plans for utility pilots	3:00–3:30
Closing reception		**3:30–4:00**
7.	Close of day 3	

1.3 Workshop Outcome Summary

1.3.1 Human Resource Time Requirements

- Development phase
    - First one takes more time.
    - need information in-house.
    - HACCP training course
    - Time depends on agency culture and organization experience with risk management.
    - 6–12 months (could be up to 18 months)
    - 0.5 FTE
    - depends on facility type (e.g., catchment, plant)
    - requires input from other parties (in-house and outside)
- Implementation phase
    - takes more time during plant commissioning
- Maintenance phase
    - 0.5 FTE
    - on-going input and review by others in-house (operation, maintenance, planning, purchasing)
    - verification
    - periodic meetings
    - review, review

1.3.2 Benefits

- QA
- due diligence/liability—defensible plan
- risk reduction/management/understanding
- information sharing
- customer satisfaction/marketing recycled water use (especially for irrigation of food products)
- could reduce regulatory requirements/monitoring
- measures business performance
- clear failure criteria and responses
- proactive facilities management to optimize performance and improve efficiency—each process, not just end-of-pipe
- use data for future budgets, facilities expansions, and upgrades
- advance wastewater industry standards
- improves facility operation
- consistency of facilities operation
- helps assess needs for processes and hardware
- certification by third party
- allows for flexible plans
- assigns responsibilities—names
- channels resources to most critical areas/needs
- offers principles and isn't prescriptive

1.3.3 What's Missing from HACCP

- depends on why you want to apply HACCP
- Focus is on health effects, not necessarily environment, aesthetics, customer service, but it can be expanded to include all of these.
- risk assessment
- guidance for multi-agency projects
- doesn't identify other measures to guarantee process performance—only uses CCPs
- doesn't define safety or acceptable risk levels
- not specific (allows flexibility, however)
- checklists for ease of use/development

1.3.4 Barriers to Implementation

- organizational culture
- organization—multi-agency
- budget, costs: benefit–cost ratio
- senior management support (including support of elected officials, boards, councils)
- stakeholder(s) commitment(s)
- lack of understanding/appreciation of cost of avoidance, incidents, value of HACCP
- validation requirements
- current regulatory requirements/framework—if add-on to permit requirements
- fear of how it will be used
- loss of flexibility of process/facilities operation—would require changed HACCP, validation
- change quality systems that are already in place

1.3.5 What's in HACCP That's Not Required?

Some schemes (WHO) have taken out CCPs but maintained critical limits or QCPs.

1.3.6 Supporting Programs and PRPs

- inspections, validation of as-built conditions, record drawings
- operator training
- chemical control register
- lab methods/analyses
- SOP
- etc.

1.3.7 Use of HACCP Jargon and Terminology

- too many letters
- "hazard" may sound scary—need to define
- could be renamed, especially to separate it from the food industry
- HACCP _____? Plan? System?

1.3.8 CCPs Designated

- For indirect potable reuse, use monitoring wells and groundwater quality as a CCP.
- For indirect potable reuse, use tracer for retention time as a CCP.
- Upstream and downstream facilities can be CCPs (e.g., reservoirs/catchments, wastewater source control).

1.3.9 Theoretical Aspects

- Risk management theory from a microbial control perspective
  - CAMRA to consider how HACCP assess and management risk—wiki
- Integrating QMRA into HACCP process
  - microbial risk estimated in situation with differing data quality
  - verification approach when you want pathogens at less than detect levels
  - risk communication in particular of uncertainty

1.3.10 Choosing the Scheme

- grades to cover
  - tertiary
  - IPR
- end uses to cover
  - irrigation of schools
  - groundwater recharge/barriers
- project/phase
  - existing/operating
  - planning

1.3.11 Getting Approval for Pilot from Utilities

- Send out example HACCP plans.
- Send out a project summary.
- Use personal contacts using WRRF members.
- up-front gap analysis of multiple systems to identify subset of systems to pilot where HACCP would add value (desktop review)
- Gain engagement from other stakeholders: WD, SD?
- Clarify the involvement and efforts of pilots.
- Justify the pilot on effort–benefit grounds.
- training > pilot to fill gaps > capture outcomes
- Is there overdesign or excess end-product lab testing—could HACCP reduce costs?
- How will the project influence permits?
- What are the perceptions of costs, effort, and benefits?
- Provide an existing Australian HACCP plan.
- one-day training of HACCP understanding for utilities that are interested in implementing
- not starting from scratch but with utilities that already have some process in system and just need to document for audit format
- Capture perceptions and values on costs, efforts, and benefits.
- One pilot to be implemented at OCWD, West Basin, and one in the states?
- Clarify the involvement and effort for the pilots.

- risk assessment—timely
- Work with consultant.
- training: 12 people for 1 day training; 12 people for workshop in risk management 2 or 3 days
- Develop procedures.
- Justify the pilot on cost–benefit or effort–benefit grounds.

Appendix B

HACCP Gap Analysis Checklist

- **Commitment from senior management**: Is there any evidence of a commitment from senior management to product quality and safety? For example, quality policy, corporate strategy, customer charter, resolution of the governing body.
- Does the business specifically allocate suitably qualified personnel to manage the QA system? Are there dedicated QA management personnel?
- Do ingredient suppliers (source control and STP) employ formal quality management systems to manage their activities?
- **Is there a recycled water product specification**: Are operational staff aware of the specification? Are customers provided with a product specification?
- **Regulatory awareness**: Is staff aware of regulatory requirements? How are changes recognized and communicated? How is compliance managed?
- **Roles and responsibilities**: Organizational structure, position descriptions, procedural instruction should clearly indicate roles and responsibilities.
- **Internal communication**: How does communication between levels of management occur?
- **External communication**: Are there processes for managing external communications to customers, regulators, and other stakeholders?
- **Emergency preparedness**: Is there a process for the declaration and escalation of incidents? Incident training, contingency plans?
- **Document control**: Is there a system to control important documents (policies, procedures, plans)? Version control, access control, archiving?
- **Process flow diagram**: There should be a verified process flow diagram of the overall process (in addition to the detailed drawings).
- **Process validation**: Is there any evidence that the existing process steps have been validated as effective?
- **Hazard analysis**: Is there a list of the hazards that exist at each step in the process? Have these hazards been analyzed in terms of risk and criticality?
- **CCPs**: Points in the process where failure is irreversible or where a hazard is reduced to an acceptable level are considered to be critical. Have such points been identified in the process?
- **Critical limits**: CCPs usually have defined performance limits or critical operational ranges. Less critical process steps may have operational limits. Are limits defined and documented?
- **Preventive measures**: For important hazards, there should be documented preventive measures or controls.
- **Monitoring and control**: For each preventive measure, there should be documentation to indicate how the measure is monitored and controlled.

- **Corrective action**: For each control measure, there should be documentation on the corrective action that needs to be taken when the preventive measure fails.
- **Traceability**: Is the distribution of the product accurately known? Are production samples held for a defined period?
- **Noncomplying product**: Are there procedures or processes in place to dispose of and control the release of noncomplying product (e.g., customer notification, regulator and stakeholder contact, system reinstatement)?
- **Verification**: Is there end-point verification testing? Is there an internal or external auditing regime that investigates the implementation and integrity of the QC system? Is there a system to follow up on audit findings?
- **Management review**: Do production staff and senior management periodically meet to review the efficacy of the quality system?
- **Product performance**: Is there any mechanism to capture customer feedback regarding the performance of the product? Is there any program to measure the sustainability of the product?
- **Feedback loops**: Are there feedback loops between the various components of the supply chain (source control, STP, Water Factory, and end users)?
- **Continuous improvement**: Are there any mechanisms for continuous improvement (e.g., excursion notices, suggestion boxes, meetings, audits)?

Appendix C

Supporting Programs

- **Standards:** Are there defined standards for material used in the production and distribution of product?
- **Maintenance:** The production process should be supported by a comprehensive maintenance regime. Is there evidence of asset registration, maintenance scheduling, maintenance work, and associated recordkeeping?
- **Training:** Are competency and training requirements documented? Is there a system to identify training needs for relevant staff? Is training carried out and are records kept?
- **Calibration:** All measuring instruments used in the process need to be calibrated. Is the calibration performed using the correct method and at the correct frequency? Are records kept?
- **External supplies:** Is there a system in place to check the quality of externally supplied material? Are deliveries supervised?
- **Contractors:** How are visiting contractors controlled? Is there a permit to work system in place?

Appendix D

Summary for Irvine Ranch Water District Michelson Water Reclamation Plant and Recycled Water System

HACCP Criteria		Plant	Distribution	Comments/Notes
1.	Commitment from senior management	5	5	Commitment is evident. Management has adopted formal mission and vision statements.
2.	QA	3	3	Implementation of QA is fragmented/decentralized rather than centralized. No dedicated resource (staff person) for utility QA. Under HACCP, a designated, dedicated resource (staff person) would be responsible for a centralized formal QA program.
3.	Source control and raw wastewater quality	5	5	IRWD and OCSD share responsibility for operation of the source control system. Industrial pretreatment and expanded/ enhanced source control quality standards apply to the collection system. Process ingredients (e.g., chemicals) are sourced from quality suppliers and deliveries are supervised.
4.	Recycled water product specification	5	5	Permit is the specification, but customer satisfaction does not appear to influence the specification (i.e., Title 22 regulations vs. customer water quality desires—lower TDS; Nonconforming Use Policy).
5.	Regulatory awareness	5	5	strong awareness of permit requirements, Title 22 Water Recycling Criteria, and Title 17 Backflow Prevention requirements
6.	Roles and responsibilities	4	5	Organizational structure and job descriptions are in place. Training and succession planning are incorporated into a well-defined organizational chart. MWRP will soon have new electronic O&M manuals, which will enhance its written documentation. Written SOP exists for the distribution system.
7.	Internal communication	5	5	
8.	External communication	5	5	

HACCP Criteria		Plant	Distribution	Comments/Notes
9.	Emergency preparedness	5	5	General procedures in place. Procedures for major treatment process failures and long-term recycled water quality problems involve reliance on OCSD for treatment and use of other raw, nonpotable, or potable water in place of recycled water.
10.	Document control	3	5	Missing centralized document control system for all district documents, although emergency procedures are centralized, controlled documents. Plant SOP is controlled by senior operations staff. More SOP and O&M procedures will be centrally documented when the electronic O&M manual and plant expansion construction are completed.
11.	Process flow diagram	5	5	
12.	Process validation	5	5	Process validation is based on permit requirements, Title 22 Water Recycling Criteria, and Title 17 Backflow Prevention requirements.
13.	Hazard analysis	5	5	Formal site-specific hazard analysis for emergencies exists. Hazard analysis for recycled water use inferred in Title 22 Water Recycling Criteria, Title 17 Backflow Prevention requirements, facilities design, and HAZOP studies.
14.	CCPs	4	4	No formal CCPs have been set, but certain activities are treated as CCPs in practice. Instrumentation for monitoring process performance and water quality is in place at critical locations and tied to the SCADA system.
15.	Critical limits	4	4	Informal limits exist for informal CCPs. Set points monitoring process performance and water quality are treated as critical limits, with automatic alarms requiring corrective actions.
16.	Preventive measures	3	4	Preventive measures for hazards exist; some are documented in writing and others are by experience.
17.	Monitoring and control	5	5	SCADA system is extensive, and evidence of monitoring and control exists; however, time did not allow verification of SOP.
18.	Corrective action	4	4	Measures are in place, but not well documented in writing. Plant operators can login remotely to make changes.
19.	Traceability	NA	5	good knowledge and control of distribution

HACCP Criteria		Plant	Distribution	Comments/Notes
20.	Noncomplying product	5	5	Out-of-spec water can be diverted to OCSD. Raw, nonpotable, or potable water can be substituted for recycled water service.
21.	Verification—process (end point)	5	5	Online instruments are regularly calibrated.
22.	Verification—internal audit	3	3	Informal decentralized approach of checks and balances provides department-to-department verification and internal audit function. Lab has internal QA with water quality department review of data. No formal QA system or evidence of formal internal audit of entire utility as a whole. No dedicated resource (staff person) for utility QA.
23.	Management review	5	5	
24.	Product performance	5	5	Recycled water use continues to increase, indicating a trend of sustainability. Customer concerns are addressed by appropriate personnel.
25.	Feedback loops	5	5	Feedback occurs between departments.
26.	Continuous improvement	3	3	State audits laboratory. No formal internal QA audits of entire utility. Unable to confirm if a suggestion box for improvements exists and what response would take place; however, general attitude of quality and improvement exists utilitywide.
Supporting Programs				
A.	Standards	5	5	
B.	Maintenance	5	5	
C.	Training	5	5	
D.	Calibration	5	5	
E.	External supplies	5	5	
F.	Contractors	5	5	

Scoring Key:

Score	Criteria
1	No evidence of meeting this HACCP checklist item was observed.
2	There is evidence of this element in some parts of the utility, but implementation is generally incomplete in the processes examined.
3	There is evidence of this element in most or all parts of the utility, but implementation is often incomplete in the processes examined.
4	This element was complete in some processes within the utility.
5	This element was complete in all or most of the utility.
NC	not confirmed
NA	not applicable in this context

Appendix E

Summary for Orange County Water District Groundwater Replenishment System

HACCP Criteria		Plant	Distribution	Comments/Notes
1.	Commitment from senior management	5	5	Strong commitment, although no formal overall quality policy. GWRS has a very proactive water quality policy.
2.	QA	3	3	Implementation of QA is fragmented/decentralized rather than centralized. No dedicated resource (staff person) for utility QA. Under HACCP, a designated, dedicated resource (staff person) would be responsible for a centralized formal QA program. However, the water quality laboratory has a comprehensive QA protocol in place as one component for state certification and a designated person with the title of QA for data oversight from the laboratory.
3.	Source control and raw wastewater quality	5	5	OCSD operates source control system. Industrial pretreatment and expanded/enhanced source control quality standards apply to the collection system. Process ingredients (e.g., chemicals) are sourced from quality suppliers, and deliveries are supervised.
4.	Recycled water product specification	5	5	Permit is the specification, plus evidence of further internal process optimization noted.
5.	Regulatory awareness	5	5	strong knowledge of regulatory requirements, Title 22 Water Recycling Criteria, Title 17 Backflow Prevention requirements, and permit requirements
6.	Roles and responsibilities	5	3	Organizational structure and job descriptions are in place. Training and succession planning are incorporated into a well-defined organizational chart. OMMP, electronic O&M manual, and SOP are used for the AWPF. For the Barrier and Forebay, more written SOP is needed, rather than reliance on experience alone.
7.	Internal communication	5	5	
8.	External communication	5	5	

HACCP Criteria		Plant	Distribution	Comments/Notes
9.	Emergency preparedness	5	5	General procedures in place. AWPF can be shut down until any problems are corrected. Back-up water supplies are available for the Barrier (potable water) and Forebay (Santa Ana River water and imported water).
10.	Document control	4	2	Missing centralized controlled system. AWPF has extensive written documentation in OMMP and online O&M manual. Barrier and recharge have minimal written documentation of major activities, SOP. More written documentation and document control are needed for HACCP.
11.	Process flow diagram	5	5	
12.	Process validation	5	5	Process validation is based on permit requirements and process demonstration.
13.	Hazard analysis	5	5	No central formalized hazard analysis compilation. Hazard analysis for recycled water use inferred in permit, Title 22 Water Recycling Criteria, Title 17 Backflow Prevention requirements, and facilities design.
14.	CCPs	5	4	AWPF has documented CCPs. Barrier and Forebay CCPs exist but are not documented in writing. HACCP system would establish written CCPs for the Barrier and Forebay.
15.	Critical limits	5	3	AWPF has documented critical limits. Barrier and Forebay critical limits exist but are not documented in writing. HACCP system would establish written critical limits for the Barrier and Forebay.
16.	Preventive measures	5	4	AWPF corrective actions are well documented. Barrier and Forebay corrective actions are not documented in writing. Under HACCP, the preventive measures for the Barrier and Forebay operations would be well documented.
17.	Monitoring and control	5	5	SCADA system is extensive, and evidence of monitoring and control exists; however, time did not allow verification of SOP.
18.	Corrective action	5	4	Barrier and Forebay corrective actions are not documented in writing. Under HACCP, the corrective actions for the Barrier and Forebay operations would be documented.
19.	Traceability	NA	5	

HACCP Criteria		Plant	Distribution	Comments/Notes
20.	Noncomplying product	5	5	AWPF can shut down until problems are corrected. Out-of-spec water can be diverted to OCSD outfall. Other water supplies are available for the Barrier (potable) and Forebay (Santa Ana River water and imported water).
21.	Verification—process (end point)	5	5	Online instruments are checked against bench-top tests. Extensive post-recharge groundwater monitoring occurs before it is extracted for potable use.
22.	Verification—internal audit	3	3	Informal decentralized approach of checks and balances provides interdepartmental verification and internal audit function. Lab has internal QA with water quality department review of data (LIMS to WRMS). No formal QA system or evidence of formal internal audit of entire utility as a whole. No dedicated resource (staff person) for utility QA.
23.	Management review	5	5	
24.	Product performance	5	5	Groundwater producers are OCWD clients and can provide feedback. In future, purified recycled water will be used for cooling water at Anaheim power plant, a new customer.
25.	Feedback loops	5	5	OCWD and OCSD have regular operations and water quality communication. Feedback occurs between departments within the utilities.
26.	Continuous improvement	3	3	State audits laboratory. No formal internal QA audits of entire utility. No suggestion box for improvements, although utilitywide philosophy encourages improvement. Under HACCP, need more established procedures, policies, notices, meetings, audits to promote continuous improvement.
Supporting Programs				
A.	Standards	5	5	
B.	Maintenance	5	5	
C.	Training	5	5	Written training program and SOP for Barrier and Forebay are missing.
D.	Calibration	5	5	
E.	External supplies	5	5	
F.	Contractors	5	5	

Scoring Key:

Score	Criteria
1	No evidence of meeting this HACCP checklist item was observed.
2	There is evidence of this element in some parts of the utility, but implementation is generally incomplete in the processes examined.
3	There is evidence of this element in most or all parts of the utility, but implementation is often incomplete in the processes examined.
4	This element was complete in some processes within the utility.
5	This element was complete in all or most of the utility.
NC	not confirmed
NA	not applicable in this context

Appendices F–H

Appendices F-H are Microsoft Word® templates. Please see the accompanying files.

Practical Solutions for Water Scarcity




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