ILSI Europe
Report Series

Considering Water Quality for Use in the Food Industry

Report

Commissioned by
the ILSI Europe Environment and Health Task Force

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ILSI

International Life Sciences INSTITUTE

CONSIDERING WATER QUALITY FOR USE IN THE FOOD INDUSTRY

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COMMISSIONED BY THE ILSI EUROPE ENVIRONMENT AND HEALTH TASK FORCE

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CONTENTS

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INTRODUCTION AND FRAMEWORK

Background

Improvements in public health over the past century have been underpinned by positive advances in the management of vital resources, such as water and food. Water quality and food safety are inextricably linked; however, freshwater resources, especially high quality freshwater resources, are becoming increasingly scarce. Water usage in North America increased by about eight times from 1900 to 1995, while global water use in 2000 was similarly estimated to be nearly three times than that in 1950 (Shiklomanov, 1998). The availability of adequate freshwater resources, in both quantity and quality, is vital to food safety and production. It plays a role in primary production (irrigation, livestock watering, aquaculture) and in processing (as an ingredient, transport medium and hygiene aid). Therefore, the food industry, in common with other industries, must address the future trends relating to this resource and move towards increasing efficiency in water use.

Water, like food, is a potential vehicle for the direct transmission of agents of disease and continues to cause significant outbreaks of disease in developed and developing countries. For example, drinking water was identified as the source of a significant and fatal outbreak of *Escherichia coli* O157:H7 in Canada (Kondro, 2000). Water is, therefore, also capable of introducing contamination into food if appropriate care is not taken. In 1970, a cholera epidemic in Jerusalem (Israel) was traced back to the consumption of salad vegetables irrigated with raw wastewater (Shuval *et al.*, 1986) and in 2006, a chocolate company located in the United Kingdom was affected by contamination of chocolate by *Salmonella*, reputedly from a leaking wastewater pipe in the production area.

Although water is just one route by which foods can be contaminated with disease-causing agents or toxic chemicals, it is potentially very important. Raw water can be contaminated with pathogens, usually as a consequence of human or animal faecal material or run-off contaminated with faecal material. It can also be contaminated with a wide range of chemicals, both natural and anthropogenic, which are of concern under some circumstances depending on the concentrations present. Contamination can arise in raw water or as a consequence of improper storage or pick-up of contaminants from distribution systems. It can also occur as a consequence of leakage from a dirty water system into a clean water system. In addition, the increasing pressure to optimise water use within food production facilities may result in the potential for contaminated water to reach food products. There is the dilemma that water can present some risks to food safety (see Section 3), but it is an essential part of food production and processing. It is, therefore, vital to minimise the risks and avoid unnecessary harm by ensuring that the necessary control measures are put in place, e.g. water safety plans and Hazard Analysis and Critical Control Point (HACCP) plans. Water quality requirements are a function of the type of food, processing conditions and methods of final preparation in the home (cooked/uncooked). They are also dictated by the use of the water within a particular process or process stream. If the water is potable[(1)], then it is probably acceptable for all food contact uses. However, not all uses require water to be of this standard and where it is possible to use other sources of water or to reuse water then the water quality requirements will need to be tailored appropriately. The aim of this document is to support this tailoring of water quality to the application in order to reduce the burden of both using water of unnecessarily high quality and/or unnecessary treatment of the water, while allowing more efficient use of water resources.

(1) Potable may be defined as water that is wholesome or will not affect the wholesomeness of the food in question. This would normally mean that the water would meet the requirements of local standards for safe drinking water or meet the requirements of the WHO Guidelines for Drinking-water Quality.

Scope

This document deals with water and the food industry including primary production and processing. It is concerned with food safety and therefore includes aspects of public health. In this context, there is recognition that the human population may be exposed to infectious agents or toxic chemicals through:

- The ingestion of contaminated water incorporated into foods.
- The ingestion of foods irrigated with, or harvested from, contaminated water.
- The ingestion of foods that have come into contact with contaminated water during processing.

The document does not specifically deal with "quality" aspects of food. Therefore, considerations such as the impact of the quality of water on the organoleptic characteristics of the final product are not formally addressed in this paper. However, there are contaminants that can result in quality problems, such as off-flavours deriving from by-products of algae or actinomycetes in raw water. The remit of this document does not include other important aspects of the subject, such as the impact on wildlife or natural eco-systems.

The Codex Alimentarius (Codex Alimentarius Commission, 2006) framework of risk analysis has been accepted and is recommended as the basis on which this document might be used. The risk analysis process consists of three components: risk assessment, risk management and risk communication. Risk assessment is dependent upon the correct identification of the hazards, the quality of the data used and the nature of the assumptions made to estimate the levels of risk. However, pragmatic and practical decisions can be made that will be essential in the development of practical risk management strategies. While minimising risk is the primary goal and extremely low levels of risk are achievable, zero risk is not considered to be attainable. Throughout the entire process, risk communication should assure the continuous information exchange among all involved parties.

Objectives

Food producers and processors require a framework based upon sound science that permits them to assess the potential for optimising water use and to determine the potential impact of using different levels of water quality on their businesses. The third edition of the WHO Guidelines for drinking water quality set microbial and chemical quality targets for potable water (WHO, 2004), and these are updated annually. Water in the food industry is currently often classified as either potable or non-potable, with most legislation simply requiring the use of potable water with little consideration of the application. It would seem logical to modify this classification to include a category that considers "suitability for intended use" to allow for the use of water of appropriate quality for a particular application. However, determining suitability for intended use needs to be based on accepted risk assessment criteria for chemical and microbiological hazards, and to be compatible with HACCP principles (Codex Alimentarius Commission, 1997; Van Schothorst, 2004). This document, which is the result of collaboration of scientific experts from academia, non-governmental organisations and the food industry, is intended as a contribution to the responsible management and use of water as an essential resource.

Structure

This document is divided into three sections. The first provides a general introduction to the setting of performance criteria and to management systems that assure that the performance targets are met. Depending on individual cases, it may be appropriate/possible for organisations to set their own performance criteria to protect public health, in other cases regulation or regulatory guidance will be more appropriate. A framework for assessing suitability of water for intended use is presented. It is important to point out, however, that this will need to be decided on a case-by-case basis and there is no intention to supersede or by-pass relevant regulations.

Section 2 covers the important question of reuse of water, which is becoming an increasingly vital means of conserving water resources and helps to provide water security for food companies.

The final section contains some detailed technical material that might provide answers to the questions posed in Section 2. However, much of this material already exists in the literature and so an authoritative reference list is provided.

SECTION 1: WATER QUALITY IN FOOD PRODUCTION AND PROCESSING

Risks from water to food

Risk estimates developed for drinking water of a specific quality may not be valid for water used in food production/processing. Factors affecting the risk may include the following:

- The pathogens of concern may be different: Pathogens of faecal origin are generally considered to be the greatest threat to drinking water whilst other pathogens can be important in food-borne illnesses, e.g. *Bacillus cereus, Staphylococcus aureus.*
- The growth of pathogens: Pathogens discharged into water sources do not normally multiply (with a few exceptions), but bacterial growth in food products can be an important factor in food-borne disease.
- The uptake and concentration of chemicals and pathogens: Concentrations of chemical and microbial contaminants in drinking water sources are generally stable or decline with dilution, but the concentration of chemicals and some pathogens can increase in foods or on food surfaces, e.g. shellfish can concentrate chemicals or pathogens in their flesh to levels higher than the ambient environment (Boher *et al.*, 1991; WHO, 2006a). Ascaris eggs and *Cryptosporidium* oocysts can concentrate on crop surfaces irrigated with wastewater (Blumenthal *et al.*, 2000; Armon *et al.*, 2002).
- Some national standards for chemicals in drinking water may include allowances for exposures to the chemical that may not be relevant to food production/processing, e.g. skin absorption or inhalation from bathing or showering, although this does not apply to the WHO Guidelines.
- Processing: Drinking water is often consumed without further processing, but water that enters the food cycle may be processed further (e.g. canning, cooking), which will reduce risk from pathogens.
- It is important that if a problem has arisen that results in product loss, then the cause should be determined. Should the water supply be responsible in some way corrective action must be implemented.

It is important to remember when establishing targets necessary to protect public health using risk analysis that risk is made up of two components: one is exposure, and the other is the severity of the hazard.

Assurance of water quality

Recently, an approach for formalising quality assurance programmes for drinking water supplies has emerged. This has included, for example, approaches based on the generic ISO 9001 Quality Standard. Havelaar (1994) proposed the modification and widespread application of the Hazard Analysis and Critical Control Point (HACCP) principles, which were formally codified by The National Advisory Committee on Microbiological Criteria for Foods (NACMCF, 1998), to drinking water supply safety. Subsequent initiatives have addressed the potential benefits of expanding these concepts more generally to water management for health (Bartram *et al.* 2001, WHO 2005). The WHO approach, also enshrined in principle in the International Water Association (IWA) Bonn Charter (IWA 2004), is called Water Safety Plans (WSPs) (see Annex 1) and is a risk-based management plan covering water supply from source to tap. The approach is increasingly being adopted by water suppliers around the world and can be applied to water supplies of any size. As with HACCP, the requirement is to identify the hazards at each stage of the process to assess the risks and to ensure that significant risks are mitigated by preventive actions that include planning for emergencies. Where barriers, such as water treatment processes, are put in place these are monitored to ensure that the processes are working properly at all times. The major differences between HACCP and WSPs for water supply are that the process is extensive and susceptible to outside influence, and that the process is continuous, providing a continuous supply in most cases. This means that reliance on final product testing is not sufficient because by the time results are available the product is usually with the consumer. Our knowledge of water quality has increased significantly and we now know that simplistic categorisation is not necessarily appropriate or conducive to efficient use of resources.

Conceptual framework

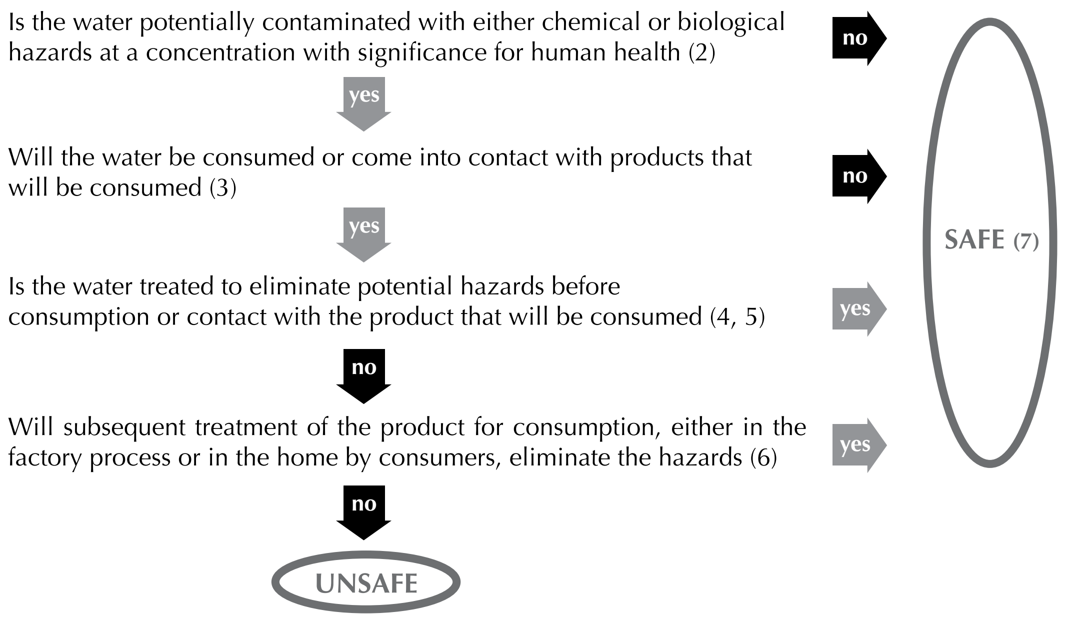
Table 1 outlines the proposed classification. There might be criteria other than microbiological and chemical composition to consider for water quality but this proposal incorporates treatments that can be used to make the water safe and "fit for purpose". Aspects that might be specific for given purposes other than food production are not addressed in this document.

Table 1. Safety classification of water "fit for purpose"

I. Potable chemically Potable microbiologically	II. Potable chemically Non-potable microbiologically
III. Potable microbiologically Non-potable chemically	IV. Non-potable chemically Non-potable microbiologically

Such a classification is best approached through a decision tree, to identify whether water is safe for the planned purpose. All decision trees are, by their nature, a guiding framework rather than a rigid structure and their use must reflect this. The decision tree on page 9 should be used by answering the questions sequentially with reference to the footnotes. The outcome can be a classification of the water according to the system proposed in Table 1, which should provide guidance on whether the water is suitable for the intended use. In some cases, a detailed risk assessment may be necessary to answer the questions. If, after a risk assessment, the answer is doubtful, it is recommended that users apply the "precautionary principle". The precautionary principle as defined in the 1992 Rio declaration (UNEP, 1992) is: "Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation". Although the precautionary principle has been developed and used widely, the key components of not waiting for scientific certainty and cost-effectiveness or proportionality of measures still stand.

Decision tree for assessing the suitability of water for its intended use (1)



1. What is the purpose for which the water is required, and who or what will be exposed to it?

   Does the water stream have the potential to come into contact with the product? If the answer is yes, at what stage in the production cycle is contact possible? In addition, it would be important to identify the receptors (e.g. the crop, livestock or humans) and the nature of the contact, whether it be as water, ice or steam.

2. Refer to guidelines and regulations to demonstrate the safety of the finished product (food law and water guidelines).

   It is important to determine what guidelines and standards exist in order to have a basis for demonstrating safety both to managers and, where appropriate, customers and regulators. Where guidelines or standards do not exist or cannot be used to inform these decisions, it may be necessary to seek or develop new guidelines ensuring that these are appropriate and properly recorded.

3. Source of water and potential hazards must be considered.

   In untreated water, there could be natural and anthropogenic hazards, both chemical and microbiological. Are substances deliberately added or not? Is disinfection practiced, is it adequate for ensuring microbiological safety, and will it result in disinfection by-products? Are chemicals added to process water, such as disinfectants (e.g. chlorine), cleaning products and substances to aid manufacture? Do they form reaction by-products? Are substances added to facilitate processing and are substances extracted from the "food"? Are boiler water additives used and can these reach the product, e.g. through leaks or non-potable steam? Is recycled water used in the food process?

4. Are there existing steps in the process that will, intentionally or unintentionally, act as mitigation steps to potential hazards and risks?

   What currently happens? What is the type of irrigation and will this minimise or act as a barrier to contact with the crop? Will there be a wash stage in potable water, or is there an existing water treatment step that will act as a barrier to either microbial or chemical hazards? Are there subsequent processing steps, e.g. peeling, that will act as a barrier to transmission of the hazard to the final product?

5. Evaluation of exposure and risk:

   Is exposure of product/consumer possible/likely? If so, how much will that exposure be and how long for?

   If there are existing standards or adequate toxicological data to determine a safe level or a microbiological risk value, are we above or below this level/value?

   If there are no standards or adequate toxicological data, is the Threshold of Toxicological Concern (TTC) (Barlow, 2005) applicable, and which one? Is the exposure expected to be above or below the TTC?
6. Can additional mitigation measures be introduced to avoid a problem by preventing or reducing exposure?

   If there is no mitigation possible and exposure is unavoidable, then further risk characterisation is required.
7. Determine the necessary steps for monitoring that the barriers and mitigation measures in place are operating properly, and identify the steps for verification that the product is safe.

Example: Risk assessment for contamination of canned soups by **Cryptosporidium** *as a result of contaminated water supply*

This example of a risk assessment is based upon a previously published review by Dawson (2000), but the information has been reorganised into a more formal risk assessment framework consisting of four main steps and consideration for the risk manager. Although the original incident was in a public water supply, the issues and approaches apply equally well to reused water or to an inadequately treated water source at risk of *Cryptosporidium* contamination.

Hazard identification

Cryptosporidium is a significant pathogen of humans causing self-limiting gastrointestinal infection in otherwise healthy people. It is usually extremely unpleasant, can last many days and, in the immuno-compromised, can cause a severe, protracted and watery diarrhoea.

Transmission of *Cryptosporidium* is via the oocysts. These are excreted in the faeces of infected animals or humans. The oocyst does not multiply outside the body (e.g. in the factory environment) thus setting it apart from many bacterial pathogens and spoilage organisms (Dawson, 2005). Between 1988 and 1998 the UK Drinking Water Inspectorate (DWI) investigated 25 outbreaks, and epidemiological evidence suggested that consumption of drinking water led to a detectable increase in cryptosporidiosis in consumers of those supplies. Of these 25 incidents, 14 involved increases in cases despite the absence of reported detection in water supplies. This failure to detect oocysts in water is probably due to the long incubation period of about seven days. This often results in a delay in taking samples for retrospective water testing, while the actual contamination period can be quite short (Dawson, 2000).

Contamination of a public water supply may occur as a result of a contaminated source with inadequate treatment, or a failure of the controlling technology (coagulation and sedimentation and/or filtration). *Cryptosporidium* spp. are distributed worldwide and have low susceptibility to the treatment processes used for most bacteria. In particular, they are extremely resistant to chlorination and some UV treatments. The most suitable technologies that might be applied in treating water in the food industry are sand or cartridge filtration (membrane filtration, 1 micron) and heat (70°C for 2 min.) (Dawson, 2000).

Hazard characterisation

Transmission of *Cryptosporidium* via water has received much attention because such outbreaks generally affect large numbers of people in a short space of time. In the majority of diagnosed cases, however, potable water is not considered to be the route of exposure. Food-borne outbreaks have been linked to direct contamination of fresh foods, but none has yet been attributed to commercially processed food (Dawson 2005).

The current view is that the number of oocysts required for an infection to result in 50% of people (ID50) lies between 10 and 1000. The ID50 for children is not known but may be lower. It is possible that the sampling method, used in the UK and elsewhere, for establishing *Cryptosporidium* contamination of drinking water (continuous filtration) may average out peaks of much higher organism density. It is, therefore, dangerous to try to relate sampling estimates of numbers in drinking water to information on infectivity (Dawson, 2000). The probability of infection in humans from one oocyst is around 0.4% (Hoornstra & Hartog, 2003) although there is some uncertainty surrounding this figure.

Exposure assessment

As well as the potential to enter food factories in water systems, the organism is likely to be found on raw materials due to their contamination in the environment. *Cryptosporidium* has been found in the faeces of birds and wild animals, providing the potential for transfer via these vectors. Although some strains may not cause disease in humans, typing is both slow and difficult and so the assumption needs to be that any oocysts could be human pathogens. There has also been at least one outbreak attributed to the transfer of the organism from contaminated water to food (CDC, 1997). Although data are sparse, many of the activities during food processing and food preparation are likely to greatly reduce the numbers of viable organisms to well below the density found in the original source (Dawson, 2000). For example, canned foods will be heated to above 70°C for 2 min. during processing, which will ensure that no viable oocysts remain in the product. Any water that is boiled in the process will similarly have been sufficiently treated to kill any oocysts present (Dawson, 2000).

It is also theoretically possible for oocysts in product cooling water to contaminate the product after heating; however, the likelihood of this occurring is low for the following reasons:

- Numbers of the organism present in the cooling water are likely to be extremely low if the source is properly treated.
- Raised temperatures of the cooling water due to heat transfer in the cooling process will inactivate the organism if the temperatures are sufficiently high.

Only very small volumes of cooling water will come into contact with the product in correctly sealed and processed cans (Dawson, 2000). An acceptable spoilage rate in properly seamed cans is between 1:100,000 to 1:1,000,000 (Adams & Moss, 1995). Unlike other pathogens that may be found in food, the oocysts cannot multiply.

Should any viable oocysts remain in the product at the time of consumer purchase, these would be inactivated during the reheating of the product before consumption, where time/ temperature combinations above 70°C/2 min. are used.

Risk characterisation

The risk of illness from *Cryptosporidium* in the final product will therefore depend on the potential for viable organisms to reach the final product and to be subsequently consumed in sufficient numbers to cause illness. Although the level of contamination in some raw materials is unknown, levels in the major ingredient, water, should be negligible, as indicated above, unless a specific incident has occurred. In the case of canned soups, the risks will be extremely low because of the additional barriers incorporated by processing temperatures and subsequent reheating by the consumer.

Risk management

Risk management is the process of mitigating the risks, taking into account all of the potential control options. *Cryptosporidium* is an organism that is resistant to some common treatment processes for the removal of water-borne pathogens. It may also breach other barriers if the challenge is particularly large and/or the barrier is not working at its optimum, e.g. particle removal processes or ingress of contaminated water into distribution. As a consequence, there is a risk that contamination of normally safe potable water sources can occur. Although the risk is normally very low in a well-run potable water supply, private water supplies taken from both some groundwater and surface water sources face the same hazard and usually much greater risks unless appropriate management action is taken.

It has to be ensured that public water supplies are properly run and that a private supply, for which a risk of contamination by *Cryptosporidium* exists is properly treated. However, a residual risk always remains and as a consequence something can go wrong and contamination will occur. The need for additional barriers will depend on the product and whether further treatment is an inherent part of processing. This will be identified by appropriate emergency planning and the development of contingency plans. Although further reduction of risk by treatment of all water entering food premises to remove *Cryptosporidium* is possible, this is not considered necessary in most cases. The basis for this rationale is that presented by the UK Group of Experts on *Cryptosporidium*, which made a number of statements about the organism in its third report, "The Bouchier Report" (Drinking Water Inspectorate, 1998). These are summarised below:

- A target of zero oocysts in drinking water is not necessary, although it will be hard to establish a safe limit. Very low levels of oocysts have been found on many occasions without evidence of any increase in background cryptosporidiosis in the community.
- The setting of a standard of less than one oocyst per 10 l (the UK drinking water standard), which is not a health-based standard, derives from experience of routine situations where concentrations of at least one order of magnitude below this standard have not triggered an increase in cryptosporidiosis in the community. The assumption is that the infective concentration may be at least an order of magnitude greater than this figure.

It is recommended that, as with any raw material, the food business obtains and updates relevant information about its water supplies in the context of the intended uses. This will allow a much more structured approach to the use of water from a variety of sources in the light of increasing pressures on the availability and cost of water in many parts of the world.

SECTION 2: POSSIBILITIES FOR WATER REUSE

Water reuse in crop production

Introduction

The gap between water supply and demand is expected to widen due to increases in population and per capita consumption. The associated environmental issues are receiving greater attention in the media, resulting in increased public awareness. One such issue involves the migration of contaminants (e.g. NaCl) into the groundwater and the associated limitation on its use for agricultural and other purposes. Most of the available fresh water is consumed for agricultural purposes. However, due to the limited availability of water, this picture is gradually changing and agriculture will soon need to rely much more on marginal water sources, including treated wastewater. The use of wastewater may be challenged on the basis of potential environmental and health risks. Therefore, its acceptability for use in agriculture is highly dependent on whether these associated risks are within acceptable limits (Gaspard & Schwartzbrod, 1995; Angelakis *et al.*, 1997). The risk of environmental pollution and contamination of crops during effluent reuse can largely be reduced by using advanced technology, such as on-surface drip irrigation. Even when wastewater is contaminated by viruses, DI and particularly sub-surface drip irrigation systems are superior to other irrigation methods due to the minimal contact between the wastewater and the exposed plant foliage and fruits (Oron *et al.*, 1991). The SDI technology may well serve as an answer to the continuing debate regarding reuse criteria, particularly in regions where it is difficult to control effluent quality (Crook, 1998; Choi *et al.*, 2003).

The fate of pathogenic microorganisms in soils and aquifers is primarily governed by their transport and persistence. These, in turn, are controlled by several factors, including (i) climate (temperature, rainfall), (ii) soil type (texture, pH, water holding capacity, cation exchange capacity, organic matter content, salinity) and (iii) the pathogen(s) involved (Gerba *et al.*, 1975; Bales *et al.*, 1991; Bitton & Harvey, 1992; Gannon *et al.*, 1991). Treated wastewater and treated domestic sewage can be reused under a variety of circumstances, particularly in agricultural irrigation (Asano *et al.*, 1992; Bahri & Brissaud, 2003). An advantage is that the nutrients contained in TWW are usually beneficial for agricultural purposes (Oron *et al.*, 1991).

Application methods for water and effluent

Table 2 summarises the characteristics of the main methods for water and effluent application.

Table 2. Qualitative comparison of treated wastewater application methods (VL very low; L low; M medium; H high; VH very high) (after Oron, 1992)

Item	Surface irrigation	Spray irrigation	Sprinkler irrigation	On-surface drip irrigation	Sub-surface drip irrigation
Evaporation losses	VH	L	VH/L	L	VL
Wind drift losses	M	L	VH/M	VL	VL
Seepage losses	VH	M	M	L	VL
Runoff generation and losses	VH	M	M	L	VL
Water use efficiency	VL	M	M	H	VH
Nutrients availability	L	M	M	H	VH
Land levelling require-ments	VH	M	M	VL	VL
Energy requirements	VL	L	H	L	L
Labour requirements	VL	L	L/M	VL	VL
Capital investment	VL	M	M/L	VH	VH
Machinery manoeuvring possibilities	VL	M	M	H	VH
Equipment deterioration	VL	L	M	M	VL
Contact of water with humans and plants	H	H	VH	L	VL
Microbial safety during effluent application	VL	L	VL	H	VH

Detailed information on these methods can be found in the following references: Brenner *et al.*, 1995; Bresler, 1977; State of Israel, 1981; Chase, 1985; Choi *et al.*, 2004; Oron *et al.*, 1991; Oron *et al.*, 1992; Oron, 1996; Tollefson, 1985.

Nutrient levels in reused water for irrigation

The nutrients present in secondary effluents reused for agricultural irrigation might confer significant advantages in that they might offset the need for artificial fertilisation. However, in terms of agricultural practice, the nutrient content might also raise fears of over-fertilisation as a result of constant dosage during the season, regardless of the growth stage of the plants. Excess application of nutrients is often associated with surplus vegetative growth and possible reduced crop yield. It is also associated with pollution of both underground and surface water sources.

One of the commoner challenges in wastewater treatment is, therefore, the removal of nutrients that might pose a direct or indirect threat to humans and aquatic life through contamination of water sources. Nutrients (primarily inorganic nitrogen and phosphorus) in effluents discharged to the environment contribute to the eutrophication of water bodies and increased levels of nitrate in groundwater.

The preferred approach should be one based on controlled and selective removal of nutrients from the wastewater, combined with their reuse for productive purposes (i.e. reclamation). There is no requirement for total nutrient removal as relatively small amounts can be retained in the effluent with minimal risk of environmental pollution. Residual ammonia concentrations of 10–20 mg/l and phosphate concentrations of 10–20 mg/l might be considered acceptable in secondary effluent applied to agricultural land, but not directly to watercourses. The annual rate of nutrient application depends on the type of crop grown, the condition of the soil and the duration of application in relation to the plant growth stage (Table 3).

Table 3. Annual rate of application of nitrogen and phosphorus kg/ha [1 kg P_2O_5 = 0.436 kg P] (after Oron, 1991)

Crop	**Nitrogen (N)**	**Phosphate (P_2O_5)**	**Phosphorus (P)**
Wheat	100–210	50–100	22–44
Corn	60–160	50–100	22–44
Potato	120–180	100–150	35–66
Sugar beet	100–140	90–140	39–61
Red cabbage, cauliflower	140–210	90–140	39–61
Kale	160–250	80–100	35–44
Tomato	120–180	60–80	26–35
Apple	20–150	0–50	0–22

Under current practice, an annual/seasonal application rate of 7000 m^3/ha of secondary effluent containing around 40 g/m^3 nitrogen appears to be fairly common. Consequently, the amount of nitrogen applied is around 280 kg/ha, which is above the mean recommended level. It would, therefore, probably be preferable to treat the effluent to a level of 10–20 g/m^3 nitrogen and add extra fertiliser if the crop exhibits nutrient stress.

Criteria for reuse

Efforts are being made worldwide to develop criteria for the reuse of wastewater (WHO, 1989, 2006b; Angelakis *et al.*, 1997). The purpose of reuse criteria is mainly to protect the community and to minimise environmental damage. Reuse guidelines have been issued in the United States, South Africa, Australia, Japan, several Mediterranean basin countries and Europe. The most commonly accepted guidelines are those published by the US Environmental Protection Agency (US EPA, 2004) and the State of California, which cover conditions similar to those encountered in other arid and semi-arid regions. The WHO guidelines (1989, 2006b) for reuse in agriculture and the FAO guidelines for irrigation with treated wastewater (FAO, 1992) are also well established and consider both the needs of the end-user and the local environmental conditions.

The standards and guidelines that cover a range of agricultural practices were primarily developed to comply with health and environmental standards. Several approaches have been adopted, including determination of the numbers of faecal coliforms applied to irrigated crops. Another approach is based on the potential exposure of crops, livestock and humans through uptake of microbial and chemical contaminants by plants. In general terms, the resulting standards for secondary effluent require a BOD ≤ 20 mg/l (biological oxygen demand) and TSS ≤ 30 mg/l (total suspended solids) when applied to industrial crops or used in restricted irrigation. The most well-known reuse criteria are those issued by WHO (1989) and US EPA (2004) (Table 4).

Table 4. The World Health Organization's microbiological criteria for effluent application to irrigated agricultural crops (WHO, 1989)

Constituents	**Group A** Irrigation of crops to be eaten uncooked	**Group B** Cereal crops, industrial crops, fodder crops, pasture and trees	**Group C** Localized irrigation of crops in Category B if exposure of workers and the public does not occur
Effluent quality			
Intestinal nematodes (arithmetic mean no. of eggs/l)	<1	<1	N/A
Coliform count/100 ml	<1000	No Standard	N/A
Mandatory treatment			
Stabilisation pond	Required	Required 8-10 days retention time	N/R
Equivalent water treatment plant	Required	N/R	N/R Pretreatment needed by irrigation technology or primary sedimentation

N/R = not recommended, N/A = not applicable

The method of effluent application and the nature of the crop are of particular importance in determining the final quality of the product. For example, spray irrigation will result in deposition of pathogens on the surfaces of the crop and may result in contamination of edible portions, while trickle irrigation constitutes a much lower risk. The risks of exposure are also greatly reduced if the crop is processed in a way that eliminates pathogens before it is consumed.

Guidelines on setting targets for the quality of water required in a variety of applications can be found in the following publications:

- Asano and Levine (1998). Wastewater reclamation, recycling and reuse: an introduction.
- Australian Natural Resource Management Ministerial Council (2000). Australia and New Zealand guidelines for fresh and marine water quality.
- Bahri & Brissaud (2003). Setting up microbiological water reuse guidelines for the Mediterranean. Paper presented at the IWA 4th international symposium on wastewater reclamation and reuses.
- Blumenthal *et al.,* (2000). Guidelines for the microbiological quality of treated wastewater used in agriculture: recommendations for revising WHO guidelines.
- Codex Alimentarius (2000). Proposed draft guidelines for the hygienic reuse of processing water in food plants.
- Mara & Cairncross (1989). Guidelines for the safe use of wastewater in agriculture and aquaculture: measures for public health protection.
- US EPA (1992). Guidelines for water reuse.
- WHO (1989). Health guidelines for the use of wastewater in agriculture and aquaculture.
- WHO (2004). Guidelines for drinking-water quality, 3rd edn.
- WHO (2006). Guidelines for drinking-water quality, 3rd edn, incorporating first addendum.

- WHO (2006). 2nd addendum to the 3rd edition of the Guidelines for drinking-water quality.
- WHO (2006). Guidelines for the safe use of wastewater and excreta in agriculture and aquaculture, 2nd edn.

The impact of certain inorganic chemicals on crop quality and soil condition must also be considered, particularly with regard to toxicity and the long-term effects on sustainable production (Table 5).

Table 5. Recommended limits for selected chemical components of reclaimed water for irrigation (EPA, 2004)

Constituent	Long term use (mg/l)	Short term use (mg/l)
Aluminium	5.0	20.0
Arsenic	0.10	2.0
Beryllium	0.10	0.5
Boron	0.75	2.0
Cadmium	0.01	0.05
Chromium	0.1	1.0
Cobalt	0.05	5.0
Copper	0.2	5.0
Fluoride	1.0	15.0
Iron	5.0	20.0
Lead	5.0	10.0
Lithium	2.5	2.5
Manganese	0.2	10.0
Molybdenum	0.01	0.05
Nickel	0.2	2.0
Selenium	0.02	0.02
Tin, tungsten, titanium	–	–
Vanadium	0.1	1.0
Zinc	2.0	10.0

A limit of pH 6, total dissolved solids of 500–2000 mg/l and a free chlorine residual of less than 1 mg/l are also recommended. The original table contains detailed comments relating to each parameter that have not been reproduced here.

Questions to be asked

Questions relating to the reuse of water in agriculture include the following:

- What is the origin of the waters used, e.g. industrial, domestic, surface, saline, others?
- What other potential water sources exist in the target region? Consideration needs to be given to transportation, costs and storage.
- What are the quality parameters of the water, e.g. physical, chemical and microbial?
- What is the application of the water, e.g. industrial, agricultural, wetlands, storage, aquifer recharge, others?

When deciding on the suitability of water used for irrigation in agriculture, the following questions have to be considered:

- The type of crops to be irrigated and, for example, whether these are industrial crops, eaten raw, eaten cooked, whether the skin is eaten, whether the fruits will be disinfected, and under what conditions and for how long they will be stored.
- The location of the irrigated fields in relation to aquifers and the risks of groundwater and environmental contamination.
- The impact on soil and sustainable agricultural production.
- The potential impact of exposure on occupational and public health.

Summary and conclusions

When attempting to optimise the use of water, particularly in regions with little in the way of high quality conventional sources, a broad view has to be taken of all relevant factors, including water quality and reliability of supply, environmental issues, public concern and safety of food production. There are two linked components to the implementation of a successful system:

- Field experiments leading to construction and maintenance of the treatment systems.
- Development and implementation of management models that take into account environmental, economic and social aspects of the system. This permits the evaluation of different approaches to the reduction of salinity, pathogens and other hazards in terms of cost/benefit criteria.

The development of sustainable agriculture requires new solutions to the problems of water supply and associated environmental challenges. This can, subject to economic considerations, be achieved by combining various treatment technologies in spite of the additional costs incurred in ensuring better effluent quality. Irrigation technology plays a significant part in such reuse of wastewater.

Water reuse in stock watering

Reused water, particularly wastewater may be used for stock watering. It is, therefore, important that consideration be given to potential contaminants. Pathogens can cause illness in stock, but can also contaminate produce, particularly when the stock becomes host to the pathogens. Chemicals, too, can be present and FAO (Ayers and Westcot, 1976) has proposed guidelines for a number of inorganic contaminants for stock watering (Table 6). One of the primary considerations is salinity and FAO (Ayers and Westcot, 1976) has indicated that waters with a conductivity of greater than 8 dS/m are of only limited value for livestock and unsuitable for poultry. Salinity of less than 8 dS/m is suitable for livestock but not for poultry, and salinity of less than 5 dS/m is suitable for both. In considering chemical contaminants, it is important to determine not only the capacity to cause toxicity to the stock, but also the capacity to accumulate in the animals or birds. Lead is one such substance, but there are a number of organic contaminants that can also accumulate. However, these are lipophilic and will normally only be present in water adsorbed to particulate matter.

Table 6. Guidelines for levels of toxic substances in livestock drinking water (after Ayers and Westcot, 1976)

Constituent	Upper limit (mg/l)
Aluminium	5.0
Arsenic	0.2
Beryllium (based on marine toxicity)	0.1
Boron	5.0
Cadmium	0.05
Chromium	1.0
Cobalt	1.0
Copper	0.5
Fluoride	2.0
Lead (accumulation may occur at concentrations of 0.05 mg/l and above)	0.1
Manganese	0.05
Mercury	0.01
Nitrate + nitrite (as nitrate and nitrite nitrogen)	100.0
Nitrite (as nitrate nitrogen)	10.0
Selenium	0.05
Vanadium	0.10
Zinc	24.0

Where water sources, including reused wastewater, contain high levels of nutrients and are held in still or slow-flowing systems then there is a significant potential for blooms of cyanobacteria to form. Many species of cyanobacteria are capable of producing toxins that can cause hepatotoxicity or neurotoxicity. There have been a number of occasions where stock or poultry have been seriously affected or even killed as a consequence of drinking water containing toxic cyanobacteria in large numbers (Falconer, 1993). This can apply to water taken from affected sources or when stock gain access to affected waters. The occurrence, toxicity and management of cyanobacteria have been considered by Chorus and Bartram (1999).

Questions to be asked

- What are the potential sources of contaminants that could reach the water?
- Will the chemical or pathogen reach an animal receptor? This may not be direct, e.g. deposition of chemicals on the leaves of plants or accumulated in plants may be of no direct concern, but if fed to livestock they could adversely impact growth and reproduction.
- Will the chemical accumulate in that animal and will it accumulate in the parts of that animal that will be used in food production? Can the pathogen infect the stock?
- Is the chemical present in sufficient concentration to damage that animal?

Water reuse in food processing

Possibilities for water reuse

In food processing a broad range of possibilities exist with regard to water management, including increased efficiency of water use and the promotion of water reuse. The latter can be made more efficient by tailoring the water quality requirements to the particular process. The major demands for water during food processing are:

- Washing / cleaning of (raw) products
- Transport of products
- Dissolving of ingredients
- Treatment of the product (e.g. alteration, separation)
- Provision of appropriate water content in the final product
- Cooling processes
- Steam generation
- Cleaning / rinsing of equipment
- Abnormal incidents (e.g. fire protection)
- Sanitation.

Generally speaking, it is possible to identify two main types of reuse relating to whether the water comes into contact with food product(s) or not. Typical reuse applications, where the water usually has no such contact, include its use in cooling and for the generation of "non-food steam". Water that does have contact with food may do so at the raw product stage (e.g. washing or transport) at intermediate stages (e.g. cleaning of equipment) or in the final product itself (i.e. residual water).

Requirements for water reuse

This is a complex subject area that might be subdivided into the following components:

Regulatory requirements

In some cases, water can be reused without pre-treatment (e.g. the use of condensates as washing water or extraction water within the sugar production process). However, in most cases, water that is recycled or reused will need to be treated to improve its quality, particularly when it comes into contact with food or beverage products or is used to clean surfaces that will come in contact with the products. The Codex Alimentarius Commission draft document "Proposed draft guidelines for the hygienic reuse of processing water in food plants" (Codex Alimentarius, 2004) provides a basis for decision making. Among other requirements, the Codex guidelines specify the following:

- Reuse water shall be safe for its intended use and shall not jeopardise the safety of the product through the introduction of chemical, microbiological or physical contaminants in amounts that represent a health risk to the consumer.
- Reuse water should not adversely affect the suitability of the product.
- Reuse water intended for incorporation into a food product shall at least meet the microbiological and, as deemed necessary, chemical specification for potable water. In certain cases physical specifications may be appropriate.
- Reuse water shall be subjected to ongoing monitoring and testing to ensure its safety and quality. The frequency of monitoring and testing are dictated by the source of the water or its prior condition and the intended reuse of the water; more critical applications normally require greater levels of reconditioning than less critical uses.

- The water treatment system(s) chosen should be such that it will provide the level of reconditioning appropriate for the intended water reuse.
- Proper maintenance of water reconditioning systems is critical.
- Treatment of water must be undertaken with knowledge of the types of contaminants the water may have acquired from its previous use.
- Container cooling water should be sanitised (e.g., using chlorine) because there is always the possibility that leakage could contaminate the product.

Some companies that are competing for increasingly scarce water supplies have found that it is more cost-effective to treat and reuse their process water than to locate new supplies (Wouters, 2001). Advanced water treatment technologies make it possible to treat water to a very high degree of purity, significantly reducing potential health risks associated with water reuse. It is quite possible to treat wastewater to such a degree that it can be safely used as a supplement in drinking water supplies, as the city of Windhoek (Namibia) has done since 1968 (Haarhoff & van der Merwe, 1995) and Singapore has introduced through its NEWater (Public Utilities Board, 1998). However, treating water to this extent is costly and, therefore, it may be more appropriate to consider the quality required in relation to the proposed use of the water, and to treat the water accordingly. Matching water quality requirements with the type of water use requires an analysis of the possible routes and potential for contamination of the food products concerned, and identification of the critical control points for preventing contamination. For example, using water of lower quality might be appropriate for washing the factory floor, but could pose a health risk if used for washing surfaces that come into contact with the food product. Should lower quality water be used for washing the factory floor, it would then be important to assess whether there was potential for misuse for washing food contact surfaces or a significant risk of transfer of contamination to those surfaces. Control would be by introducing fail-safe methods of water use or by adjusting the water quality to control the contaminants of concern, e.g. high microbiological quality, but a lower chemical quality. Therefore, as part of developing a framework for water reuse in food production/processing this should be integrated into existing HACCP programmes.

Public health issues

Personal health and hygiene play a critical role in controlling microbial contamination. Faecal contamination and orally transmitted diseases are of primary concern. Workers can spread these diseases during the growing, harvesting, sorting, processing and packaging of foods. Infected workers have been implicated as the source of several food-borne outbreaks (EEA/WHO, 1997). However, some outbreaks have been directly attributed to the quality of the water used (e.g. recent outbreaks of cryptosporidiosis in the USA and Australia).

One additional problem is that end-product water quality monitoring, particularly for microbial contaminants, does not, as yet, take place in real time. It is, therefore, vital to ensure that appropriate barriers are in place to ensure that contamination is prevented. While end-product monitoring is important, the cost of lost products through contamination can be significant and the release of contaminated products to the public can be devastating to a company. In assessing the hazards and risks of microorganisms, it is important to take into account the behaviour of microorganisms under conditions of nutrient limitation. For example, Brown & Barker (1999) reported that in the natural environment microorganisms often exist in a nutrient-deprived state that confers increased resistance to antimicrobial substances in both free-floating (planktonic) and attached (biofilm) communities (see Section 3: Microbial hazards). It would, therefore, be important to consider the potential for such organisms in the external water supply or from internal sources that could provide a source of contamination of the final product and whether this would pose an unacceptable risk to consumers' health.

Technical requirements

There are a number of technical requirements that apply to cooling and washing water as well as to steam generation. The water used in cooling devices should be low in mineral content, particularly with regard to hardness, to prevent scaling. The pH should range from neutral to slightly alkaline. Chloride concentrations should be sufficiently low to prevent corrosion, while still being high enough to act as a residual biocide where this is intended. Microbiological standards and the use of biocides should be reviewed regularly. Water for washing should not contain excess organic matter, because this may provide an energy source for the growth of microorganisms. Such water may also have a high pH (11–12) to limit biological growth, e.g. during the washing of beets in the sugar industry. Water in steam boilers should also have a low mineral content and the requirements relate to the prevention of scaling and reduction in corrosion, e.g. through the use of low oxygen concentrations and the application of biocides, dispersants/sequestering agents, oxygen scavengers and anti-foaming agents.

With regard to the use of steam, it is also necessary to distinguish between "non-potable steam" (steam without direct or indirect contact with the product) and "potable steam" which has direct contact with the product and is derived exclusively from potable water. In many countries reference is made to the US 3-A sanitary standard (Anon, 2004), which defines steam of culinary quality. The "non-potable steam" may be defined by its water source and entrained substances that might have originated in the boiler house. Such substances must be formally approved in line with the relevant consumer safety standards. If these are not met then purification may be achieved by entrainment (removal of particles of 20 µm and larger using a cyclone or steam filter) or by filtration (particles < 5 µm).

Questions to be asked

- What is the proposed reuse? Will the water come into contact with food or will it be used as a non-contact processing aid (e.g. coolant)?
- What are the regulatory, consumer safety and technical requirements for the water in the proposed reuse application?
- What is the starting quality of the intended reuse criteria and what treatments or controls can be applied so that it meets the criteria defined in the previous question?
- What monitoring procedures need to be put in place to adequately monitor the performance of the treatments and/or controls?
- What procedures need to be put in place to overcome existing technical difficulties, such as chemical or biological fouling (e.g. biofilms)?
- What measures need to be taken if a deviation from the required quality is detected?
- What changes to availability or cost are likely in the future and may alter the current situation (e.g. proposals in Brazil to charge industry for water abstracted from either groundwater or rivers)?
- What changes to water supply quality are likely in the future (e.g. salination of groundwater)? What treatments will be required to ensure that the water meets the necessary standards?
- What modifications could be incorporated into either existing or new equipment (e.g. appropriate filters on bottle washers) or existing or new process lines to maximise the opportunities for water reuse?
- What regulatory conditions encourage (or discourage) optimised water use?

Case studies

The sugar industry

The production of sugar is a water intensive process. During beet sugar production up to 22.5 m^3 of water per tonne of beets may be required. This demand may be subdivided into the categories shown in Table 7.

Table 7. Water consumption in the sugar beet industry (Hoffmann-Walbeck, 1985, Jördening, 2000)

Water type	**Consumption (l water/t beets)**
Flume water	5000–8000
Washing water	1500–2500
Earth transport water	150–250
Juice extraction	300–400
Juice purification (sweet water)	120
Condensation	4000–6000
Steam generation	40
Cleaning	20
Ion exchange (thin juice softening / desugarization of molasses)	50–130
Cooling and pump sealing water	400–5000
Total consumption	11,580–22,460

However, the industry demand for fresh water (i.e. well, surface or tap water) during production has decreased in the last 20 years to nearly zero, reaching a point where no further optimisation is possible. This has been achieved by adopting several measures, including:

- The internal recycling of water so that water used for washing beets undergoes a mechanical cleaning to remove soil organic matter, and water used to operate barometric condensation is recycled via cooling towers.
- Restructuring of factories to separate raw sugar and white sugar processes so that major savings are made in water consumption.
- Reuse of the original cell water in the sugar beet itself as condensate (about 750 l/t beet) for beet transport and cleaning, juice extraction, purification and crystallisation, make-up water in cooling towers and for cleaning.

The malting industry

This industry uses a variety of soaking processes and the resultant wastewater output varies accordingly. However, an integrated approach (Kraft, 1997), using a microfiltration unit, results in water that can be returned to the treatment process (BOD about 5 mg/l, ammonia less than 1 mg/l) with acceptable microbiological population estimates and low sludge-production. This reduces the demand of fresh water.

The beverage industry

The greatest demand in this industry comes from the bottle-washing process. The aim is to maximise the recycling of water through filtration and/or nanofiltration and the regeneration of surfactant. Other water recycling-systems now under consideration have made it possible to reduce the average chemical oxygen demand (COD) load of the inflow flushing water from 900 mg/l to 18.5 mg/l in the outflow. Reductions of more than 90% have been achieved after five days of failure-free operation (Rosenwinkel, 2000).

SECTION 3: TECHNICAL SUPPORT INFORMATION

Microbial hazards

Introduction

The "potability" of water, or requirement for drinking water quality, is normally encompassed in legislation (European Commission, 1998; US EPA, 2000) covering critical chemical, physical and microbiological standards, although there can be significant variation in the number and levels of chemical parameters. Most do not have specific values associated with pathogens and rely on the principle of indicator organisms, particularly *E. coli*. It is also important to be aware of the basis for a particular standard, as not all standards are health-based and there may political or technical considerations. In the absence of any such local legislation, then the minimum acceptable standard should be taken from WHO Guidelines (WHO, 2004), which are health-based. WHO has also introduced the concept of Water Safety Plans (WSPs), which are adapted from HACCP and require that the hazards are identified and the appropriate barriers are put in place to ameliorate the risks. In the case of microbial contaminants, the reliance on indicator organisms does not provide a means of ensuring the safety of a water supply since pathogens, such as *Cryptosporidium,* may still be present in the absence of indicators if the final barrier, often chlorine, is insufficient to kill the oocysts. Removal by coagulation/sedimentation and filtration is the key to removal of *Cryptosporidium* and so operational monitoring of the processes to ensure that they are working properly at all times is much more effective as a means of ensuring safety. However, this must be combined with procedures to ensure that contamination subsequent to treatment cannot occur. In addition, as indicated in Section 1, monitoring for indicators takes only a small and relatively infrequent sample in relation to the totality of supply and usually only provides results after a time delay.

List of hazards

Water has long been recognised as a vehicle for the spread of serious infections and diseases, particularly those associated with contamination by human and animal excreta. In spite of acquired knowledge, and the means to prevent such illnesses, they remain a constant threat in many parts of the world. It would be beyond the scope of this document to produce a comprehensive catalogue of potential problem organisms, as it would rapidly become out of date. The recent isolation of *Asaia* sp., an unusual spoilage organism from fruit-flavoured bottled water (Moore, 2002), is an indication that new organisms are continually emerging.

It is possible, however, to make some generalisations about the organisms that might be encountered, including those listed below:

- Bacterial pathogens, e.g. *Vibrio cholerae*, *Salmonella typhi*, *Shigella* spp. *Campylobacter* spp. and pathogenic strains of organisms such as *E. coli.*
- Viruses, especially enteroviruses (including Rotavirus, Norwalk, Small Round, Calciviruses, Adenoviruses, Hepatitis A.
- Protozoa, especially *Giardia* spp., *Cryptosporidium* spp., *Cyclospora* spp. and *Entamoeba histolytica.*

Sources of hazards

In addition to the microbial pathogens that result from contamination of water (at source or subsequently in the distribution system) by human or animal faeces, the food industry is also faced with challenges from other microorganisms, such as algae that have long been of concern in water supply. These organisms are no longer considered to be a problem merely because they block filters and slow the process of water treatment. A combination of freshwater eutrophication and particular weather conditions has resulted in an apparent increase in the incidence of nuisance blooms, particularly of cyanobacteria, most of which should be considered potentially toxic. Control depends on protection of surface waters from discharges containing nutrients (particularly phosphates), management of water bodies by destratification and mixing, appropriate treatment of water (e.g. by activated carbon and ozone) and protection of small water bodies from light, where feasible. In the marine environment, toxic dinoflagellates have been responsible for poisoning incidents associated with shellfish. In both cases prevention (i.e. the reduction of nutrient loading by sewage and other sources) can provide a solution. However, for the successful prediction of potentially hazardous events recognition of the role of physical factors (e.g. water mixing as a result of prevailing weather conditions) in a water body, particularly fresh water, is essential (Reynolds, 1993).

Routes of contamination

The three main sources of water for the food industry are treated municipal supply, ground water and surface water. Two of the most significant microbiological safety hazards are contamination of source water and of supply systems subsequent to treatment, by sewage and animal manure. This is usually detected by the presence of *E. coli*, which is also used as a means of checking the quality of the final water. However, to ensure that treatment is working adequately, other indicators such as turbidity, particle numbers and disinfectant residuals are used to provide continuous data. Contamination of the public supply by water-borne protozoan and other parasites occurs less frequently, usually as a result of failure of control systems, particularly coagulation, sedimentation and filtration. In addition, there may be problems associated with chemical contamination of the water, particularly organic by-products from algae that can interfere with treatment processes. One of the major problems faced by the industry is biofilm formation, which can cause significant problems in pipe-work in production facilities, particularly because biofilms are a challenge for sanitation and cleaning. For more information on biofilm formation and control, see the following references: Ganesh Kumar & Anand, (1998), Gibson *et al.,* (1995a), Gibson *et al.,* (1995b), Zottola & Sasahara, (1994).

As emphasised above, the standards required for drinking water might not be met or be necessary for all of the different stages of food production. However, it is essential that all procedures ensure safety for the intended use. This implies that an adequate monitoring and verification system must be in place to demonstrate that control of the quality of water coming into the process, whether it is from the public water supply, a private water supply or reused water, has been achieved at all times. The following are provided as examples:

- Rinsing may be either a pre-rinse, prior to cleaning or a final rinse after disinfection prior to production. As a minimum the final rinsing water must be of microbiologically potable quality although, for some products an even higher microbiological standard may be required. This may involve the use of chlorine (e.g. 0.5 mg/l residual-free chlorine) or application of a food grade preservative (e.g. food acid) to protect the process line until the next production run. In microbiological terms, the final rinse is the most critical stage as this contains the risk of recontaminating a disinfected process line.
- Pasteurisation or sterilisation treatment may also be used to deliver water of the required standard. To maximise water use, the final rinse water may be recovered and subsequently used for pre-rinse. However, the conditions of storage of pre-rinse water obtained in this way need to be such as to prevent microbial growth.

Determining the possible routes of contamination requires that the process is mapped and that all of the possible points of contact between contaminated water and the product are identified. This could include a range of possible scenarios, such as the potential for pipes carrying contaminated material developing leaks that result in transfer of contamination. This was the suggested source of contamination of chocolate with an unusual strain of *Salmonella*.

Exposure

Although microbiological standards for different food products may vary, this section concentrates on the minimum requirements for product water, based on WHO guidelines for safe drinking water.

Table 8 provides microbiological limits and guidelines for monitoring and verification of the various water types within a factory. It should be stressed, however, that all requirements for microbiological monitoring and verification must be derived from the HACCP study. Ideally, monitoring should not be based solely on microbiological testing, as this is frequently retrospective, but should also include the measurement of physical/chemical parameters. These include the temperature in relation to pasteurisation and chlorine concentration in relation to disinfection, particularly since drinking water supply is a continuous process and sampling can only give limited information. A thorough assessment should be carried out to ensure that all hazards have been identified and that appropriate procedures/controls have been put into place. In situations where water comes into contact with a product, either deliberately or accidentally, it is essential to ensure that this water does not introduce safety hazards.

Table 8. Monitoring and verification of the various water types within a factory

Water	**Target (indicator) organisms**	**Guideline value**	**Frequency**
Municipal water which normally means delivered to a potable standard, at intake point	Coliform bacteria (membrane method) Standard plate count 22°C Standard plate count 37°C	≤ 1/100ml ≤ 100/ml ≤ 10/ml	As determined by HACCP
Municipal and well water at intake point after treatment using a validated process	Coliform bacteria (membrane method) Standard plate count 22°C Standard plate count 37°C	≤ 1/100ml ≤ 100/ml ≤ 10/ml	As determined by HACCP
Product make up water	Depends upon subsequent process	–	–
Chilled circuits (closed), unpreserved*	Coliform bacteria 30°C Standard plate count 22°C	≤ 1/ml ≤ 1000/ml	As determined by HACCP
Chilled circuits (closed), preserved. Water circuits with a concentration of glycol (PPG) of > 25% are regarded as preserved	Coliform bacteria 30°C Standard plate count 22°C Check preservative conc.	≤ 1/ml ≤ 1000/ml	As determined by HACCP Weekly if continuous is not an option
Hot water circuits	None, check temperature, storage at 60°C and distribution at 56°C	–	Continuously
Final rinse water	As product make up water. If final rinse water is preserved, check concentration of preservative. Options: chlorine 0.5 mg/l, citric acid 0.3%	For aseptic processes sterility is required	As determined by HACCP
Cooling water for canning	Coliform bacteria 30°C Standard plate count 22°C Chlorination	≤ 1/ml ≤ 100/ml 2–10 mg/l	As determined by HACCP Daily if continuous is not an option

**Only in rare cases can closed chilled circuits remain unpreserved, as growth of psychrophilic microorganisms (*Pseudomonas *spp.) will occur to unacceptable levels.*

For the efficacy of various treatments to remove microorganisms, see Table 9.

Table 9. Inactivation values for various microorganisms by disinfectants (Dawson, 1998)

Disinfectant	Organism	Contact time (Ct) value for 2 log inactivation (mg min/l)
Free chlorine pH 6–7	*E. coli* Poliovirus *Cryptosporidium*	0.034–0.05 1.1–2.5 7200
Hypochlorite pH 10	*E. coli* Poliovirus *Cryptosporidium*	0.9 3.5 –
Chlorine dioxide pH 6–7	*E. coli* Poliovirus *Cryptosporidium*	0.4–0.75 0.2–6.7 122 (1.57 log)
Ozone pH 6–7	*E. coli* Poliovirus *Cryptosporidium*	0.02 0.1–0.2 4.3–17
Preformed chloramine	*E. coli* Poliovirus *Cryptosporidium*	95–180 768–3740 9600
UV (mWs/cm^2) for 99% kill	*E. coli* Poliovirus *Cryptosporidium*	9.0 22 –

For the inactivation of microorganisms through heat, see Table 10.

Table 10. Typical D-values (heat)

Organism	Temperature (°C)	D-value (amount of heating time needed to obtain a 1-log reduction) (min)
Bacillus cereus	100	5
Clostridium botulinum	120	0.1 – 0.2
E. coli	60	1.5
Salmonella	65	0.01 – 0.25

Chemicals in water used in food processing

Introduction

There are circumstances under which undesirable chemicals present in water used in food processing could contaminate the food chain. The increasing pressure on water resources will mean that the reuse of water becomes a potential source of such contaminants, and it is essential that this does not impact on safety. As far as human health is concerned it is therefore important to carry out an assessment to identify the hazards, to characterise the risks and to determine the interventions that might be necessary to ensure that hazardous contaminants do not reach the consumers at unsafe levels through consumption of contaminated product.

As far as environmental risks are concerned, the excessive use of water in crop production may lead to salination of the land and/or the leaching of essential nutrients. When those nutrients include nitrogen and phosphorus and they leach to still or slow-flowing surface water they may lead to excessive growth of undesirable algae (see Section 2: Water reuse in crop production). The presence of some metals and inorganic constituents, such as boron, may also result in toxicity to crops.

The reuse of wastewater may be direct (e.g. irrigation with treated wastewater) or indirect. In the latter, wastewater is discharged to a river, lake/reservoir or groundwater aquifer, which provides the opportunity for dilution and additional natural purification. Direct reuse implies that the wastewater receives little dilution but is treated and used again. Where the reused water enters a cycle in which it is reused over and over again, there is a need to consider the possible build up of contaminants.

List of hazards

Chemical hazards depend on the substances of concern, their adverse effects, target populations and conditions of exposure. It is, therefore, important to consider how a particular substance can reach the consumer and whether it can reach concentrations of concern for human health. The chemical issues that have affected the food industry, outside those giving rise to problems of acceptability, have most frequently been related to long-term exposure, because it is usually difficult to achieve the high concentrations associated with acute toxicity. The small quantities usually involved in most circumstances mean that effects are only evident after a long period of time. Most of the standards for contaminants in food and drinking water are based on risk assessments for long-term exposure.

The routes of contamination could be very important, as will be the extent of exposure of consumers to the end product. The potential for levels of concern will also depend on the circumstances. For example, irrigation would be less likely to give rise to sufficient concentrations of arsenic or fluoride to be of concern to humans, but the use of a water source high in these elements to make a liquid food or beverage could result in much greater exposure.

The categories of hazards may be defined as follows:
- Toxic to livestock
- Toxic to fish, shellfish or crustaceans in aquaculture
- Toxic to crops
- Accumulates in fish, livestock, products from livestock (e.g. milk, butter, cheese, eggs) or plants
- Causes deterioration in crop quality
- Toxic to humans (whether it be workers or consumers).

The full list of potential chemical contaminants (both organic and inorganic) is too long to include here and ranges from organic compounds, such as crop protection products, to inorganic contaminants including:
- Aluminium (acid soils, phytotoxic)
- Arsenic (phytotoxic, toxic to humans)
- Boron (essential for plants but phytotoxic at higher concentrations)
- Cadmium (phytotoxic and uptake by some crops, toxic to humans, accumulates in livestock)
- Fluoride (toxic to stock in fodder and on pasture, potentially toxic to humans from high concentrations in source water)
- Iron (reduction in available phosphorus and molybdenum)
- Lead (secondary toxicity in livestock, toxic to humans)

- Lithium (phytotoxic, toxic to humans)
- Manganese (phytotoxic in acid soils)
- Molybdenum (toxicity of forage to livestock)
- Nickel (phytotoxic in acid soil)
- Selenium (toxicity of forage to livestock)
- Zinc (phytotoxic in acid soils).

The concentration as dissolved salts of the above inorganics, may be adjusted according to the methods proposed by the Australia and New Zealand guidelines on fresh water quality (ANRMMC, 2002) and the US EPA guidelines for water reuse (US EPA, 1992) for purposes of irrigation. Pesticides, particularly herbicides, may pose a particular hazard with regard to crop sensitivity. Municipal wastewater often contains hormones that may cause feminisation of fish stocks (Gross-Sorokin *et al.*, 2006). A significant number of potential chemical hazards are addressed in the WHO guidelines for drinking water quality (WHO, 2004).

There is an additional difficulty relating to chemical contaminants and that is the public concerns around acceptability. Although there may be no scientific basis for such concerns, the customer perception may, on occasion, override this. Such concerns are usually apparent through the attitude and reports in the media.

Sources of hazards

Hazard identification requires a structured and logical assessment of the possible sources of chemical contaminants followed by determination of the potential toxicity of each substance.

The potential sources of chemical contaminants include the following:
- Natural sources, e.g. minerals in the source water
- Toxins from cyanobacteria
- Chemicals in source water as a consequence of anthropogenic activity
- Chemicals in wastewater intended for reuse
- Chemicals from materials used to store water or transport water, particularly metals.

Although the management measures may differ for various sources, the hazard identification and assessment of process intervention are very similar. The first stage in hazard identification is the determination of the presence of chemicals in the source of water, whether this is a well, a river, a stream, a lake or pond or treated wastewater. A first step in such an assessment would be the consideration of activities in the catchment area, including the chemicals used.

Well-water may contain chemicals from the rock strata through which the water has percolated. Some of these naturally occurring chemicals may be hazardous and would be of significant concern to humans or animals, if present at sufficient concentration. However, groundwater may also be vulnerable to contamination from both agriculture and industry. In particular, nitrate and some pesticides are relatively mobile and can leach to ground water. The use of irrigation, particularly in excessive amounts, can give rise to contamination of groundwater by leaching of minerals and nutrients from the soil.

Although rivers and lakes may naturally contain high concentrations of minerals, they may also receive run-off from agriculture and from urban areas. However, one of the most significant sources of chemcal contaminants in surface water is from the discharge of wastewater from industry and from sewage treatment.

Exposure

For a hazard to become a risk it is required that there is exposure to the organism of concern to a sufficiently great amount and for a long enough period. While exposure from drinking water and beverages can be relatively straightforward to assess, exposure under other circumstances may be more difficult to estimate.

Some examples of circumstances in which contaminants in water have resulted in either damage to crops or, more significantly, to serious consequences for health are listed below:

- The discharge of wastewater from a mine in Japan resulted in the accumulation of cadmium in rice when the water was used downstream in paddy fields. This resulted in the development of itai-itai disease in the local population.
- Mercury may also accumulate in aquatic life, giving rise to toxicity in those with a high fish diet. Methyl-mercury discharged in wastewater was accumulated in fish in Minamata Bay with a significant impact on the health of local communities whose staple diet was fish.
- Still or slow-flowing surface waters may become eutrophic due to the discharge and run-off of nutrients, particularly phosphate, and give rise to blooms of cyanobacteria or blue-green algae. Besides producing substances that give rise to undesirable taste and odour these organisms frequently produce toxins. There have been numerous instances in which livestock drinking water contaminated with toxic cyanobacteria have died, including intensive rearing units in the Darling River Basin in Australia.
- Cyanobacteria can also give rise to polysaccharides that can interfere with water treatment and to substances that can cause severe taste and odour problems. This has resulted in contamination of soft drinks and the subsequent precipitation of floc that caused spoilage of the product.

Risk assessment

Exposure to a hazardous chemical does not necessarily mean that there is a significant or unacceptable risk to human, animal or environmental health. In the process of risk assessment, the actual exposure to a given chemical (expressed as concentration or dose) should be compared to exposure levels that are considered safe. This is determined at the hazard characterisation stage (e.g. dose-response analysis leading to the establishment of health-based guidance values, such as Acceptable Daily Intake (ADI) or Tolerable Daily Intake (TDI), drinking water guidelines, etc.) (Benford, 2000). An acceptable daily intake is an estimate of the amount of a substance in food and/or drinking water, expressed on a body weight basis, that can be ingested daily over a lifetime without appreciable health risk. This may also be expressed as a weekly or monthly value.

Unlike microorganisms, chemicals cannot multiply but they can accumulate. There are a number of factors that impact on the concentration of a chemical in water. These include the solubility of the chemical, the hydrophobicity of the chemical and the presence of particulate matter to which it can adsorb and the degradability of the chemical by biological or physicochemical processes. Therefore, one important part of the risk assessment is the determination of the potential of a chemical to concentrate in, and remain in, the product through the process from production to consumption.

The risk assessment process requires consideration of use and whether the hazardous chemical can reach a target organism that will be susceptible to its effects. The same basic process is used whether considering phytotoxicity, human toxicity or toxicity to stock. However, the key is to ensure that the risk assessment considers the specific circumstances surrounding the critical target organism. A substance that is phytotoxic, but not toxic to animals, might be of low risk in stock watering but a high risk in irrigation. The type of irrigation is also important, e.g. spray irrigation can give rise to high risks from substances taken up through the leaves, although the substance may be of low risk through channel or trickle irrigation.

The concentrations of a chemical that can cause adverse effects will depend on the critical target organism. Fish, for example, can be susceptible to concentrations of substances well below those that would be considered of no concern for human consumption. In addition, different types of livestock have different susceptibilities to some essential minerals that may be found in water and in irrigated fodder crops. It is therefore important to assess which organisms/populations will be the critical targets and to base the risk assessment in specific circumstances around them. There may be more than one critical target organism/population associated with a specific set of circumstances.

To assess the risk associated with the presence of a given chemical in water its concentration in water (actual exposure) should be compared to health-based guidance values, i.e. standards or guidelines (e.g. WHO guidelines for drinking water quality or national standards when appropriate). There are also standards for food that will provide a basis for determining whether there is an unacceptable risk. WHO for example uses TDIs for drinking water and a range of other contaminants and ADIs, developed by The Joint WHO/FAO Expert Committee on Food Additives and Contaminants (JECFA) or The Joint WHO/FAO Meeting on Pesticide Residues (JMPR), for substances that are used in food production and food processing.

In the absence of health-based guidance values or established standards for a given chemical, alternative approaches can be used to: (i) screen out substances of low toxicological concern based on their level of exposure (threshold of toxicological concern, TTC) (Barlow, 2005) or (ii) manage the exposure to chemical hazards in case of uncertainties in the risk assessment or in the absence of full scientific rationale (e.g. ALARP, ALARA, precautionary principle approaches). There exist a rationale and modalities for appropriate use of the TTC approach, which are described in detail in Kroes *et al.*, 2000; Barlow *et al.*, 2001; and Kroes *et al.*, 2004.

Process interventions

Overview of wastewater treatment technology

A critical element of reuse systems is the efficient use of wastewater in a manner that ensures the maintenance of good health in the general population. Typical industrial wastewater treatment consists of a combination of physical, biological and chemical processes to remove solids and organic matter, and, if necessary, pathogens, metals and nutrients from wastewater. General terms used to describe different degrees of treatment in order of increasing treatment level are preliminary, primary, secondary, tertiary and advanced treatment. A disinfection step for control of pathogenic organisms is sometimes the final treatment step prior to distribution or storage of reclaimed wastewater, however, such a step may generate other contaminants, such as chlorination by-products. Wastewater reclamation, recycling and reuse treatment systems are usually derived by applying technologies used for conventional wastewater treatment, but increasingly more advanced technologies, such as membrane filtration, more usually associated with drinking water treatment, are being introduced. The goal in designing a wastewater reclamation and reuse system is to develop an integrated cost-effective scheme that is capable of reliably meeting water quality objectives. The degree of treatment required in individual water treatment and wastewater reclamation facilities varies according to the specific reuse application and associated water quality requirements (Asano & Levine, 1998, 2007).

The quality of a biologically treated wastewater is generally insufficient for applications like agriculture and municipal drip-irrigation systems, or for reuse within the production process. Therefore, additional treatment processes and operations may be required in certain water reuse applications for removal of chemical contaminants and/or removal or inactivation of microbial pathogens. Table 11 presents some typical treatment alternatives for given challenges (the list is not exhaustive).

Table 11. Treatment options

Challenge	Treatment option	Advantage	Concern	For details see
Microbiological hazards	Chlorination	Easy to handle	Resistant organisms, chemical by-products	USEPA EPA 832-F-99-062
	Ozone	Very effective	Complex technology, bromate formation	USEPA EPA 832-F-99-063
	UV	Easy to handle	TSS, turbidity and colour may render it inefficient	USEPA EPA 832-F-99-064
	Membranes (Ultrafiltration, nanofiltration)	No by-products, no smell, no taste	Costs, fouling	
Suspended solids	Granular media filters	Low cost, readily available, simple and effective. Large volume, low pressure.	Require regular maintenance	
	Screen filters	Widely available in specialised materials.	Relatively coarse separation. Not suited to heavy loads, clogging.	
	Tubular screen filters	Robust and offer repeated use.	Selection of screen material must match process conditions.	
	Membrane (Microfiltration, ultrafiltration)	No by-products, no smell, no taste	Higher operating costs, fouling	
Organic matter	Advanced biological treatment (e.g. biofiltration)	Low cost	Only for biodegradable substances	
	Adsorption (PAC, GAC)	Very effective for non-polar substances	Costly, residuals (spent carbon)	
	AOP (advanced oxidation processes)	No residuals produced	Formation of unknown (biodegradable) compounds	
Inorganic compounds				
Heavy metals	Flocculation/ precipitation		Chemicals used increase salinity	
Salinity	Ion-Exchange	Effective	Costs, salt increase	
	Reverse osmosis	Effective	Residuals to be disposed may need to be treated to reduce corrosivity	

CONCLUSIONS

The problems caused by pressures on water supplies mean that the food industry is being forced to consider both more efficient use of water and alternative sources of water. It is also necessary to minimise the use of water in both production and processing, and this will inevitably lead to reuse of water in both. It is, therefore, necessary to consider water quality in terms of its fitness for purpose. Such an approach means that the extended HACCP approach of WSPs becomes a valuable tool in helping to identify the hazards (both microbiological and chemical), to assess the risks posed by the hazards and to identify means of controlling those risks to within acceptable levels defined by WHO and national and industry standards.

Since the process begins with incoming water this means looking beyond the farm and the factory to the sources of water, including building relationships with local drinking water suppliers, where this is the source. It also means that there will be a requirement to understand water supply within the factory to ensure that contamination cannot occur since the adverse impact on the product and the reputation of the company can be very damaging. The procedures and issues discussed in this document provide a basis for companies to develop and improve their own procedures and management of water.

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ANNEX 1

Drinking-water safety and Water Safety Plans as a part of assuring safety

The Framework for Drinking Water Safety and Water Safety Plans (WSPs) was introduced as a part of the third edition of the WHO Guidelines for Drinking Water Quality and is supported by the International Water Association Bonn Charter. The concept is based on similar principles to HACCP but extends from the catchment area to the tap and provides a means of both identifying and managing risks to drinking water quality in any supply. This means that there is a change from reliance on end product or output monitoring to developing management plans that ensure that the supply provides a continuous supply of verifiably safe water. The primary difference between food production and water supply is that the former is usually a batch process while the latter is a continuous process. However, for food production and processing considering a wider range of hazards and the risks that they pose is a valuable step and such an understanding provides additional security.

In the current climate of pressure on water resources and the requirement to use water from new sources and more efficiently there is the potential for new hazards and the exacerbation of risks from existing hazards. In many cases the industry has responded to new hazards after they have caused problems, but introducing WSPs provides a means of anticipating hazards and risks. The WSP approach is laid out in a number of documents from WHO but it begins with an assessment of the system from source to tap, including mapping the whole system. For many large water supplies this is a complex activity because distribution systems allow considerable flexibility in water supply and often allow water from different sources to be switched around the system. The system assessment is supported by effective operational monitoring and management. For the food industry using water from a public supply the key issues would be to develop a relationship with the water supplier as a major stakeholder, to understand the nature and quality of the supply and to be sure the supply can deliver water of the required quality. Knowing the threats to the water supply and understanding the security of the supply will determine what additional barriers may be considered necessary to protect the supply to the processing plant. There would also be a need to develop a management system by which the food or beverage company would be alerted to any problems at an early stage. As with all raw materials there is a quality assurance requirement. Within the food processing plant it is important to carry out a system assessment, mapping the system and determining where any threats may lie, the sources, or potential sources, of any contaminants and all of the potential routes of those contaminants into the product, including materials used in contact with water. Such an approach needs to be rigorous and comprehensive so that the water supply and the wastewater systems are all fully understood. Operational monitoring and management of the system then provides a sound basis for ensuring that any water efficiency options and reuse of water will not give rise to contamination of the product and that the appropriate physical and treatment barriers are in place and can be shown to be operating correctly.

With regard to private water supplies, security and safety begins in the catchment. This applies to both agriculture and food processing and will require involvement with other stakeholders in the catchment, whether this is surface water or ground water. This is particularly important for groundwater supplies because while it is understood that surface water is vulnerable to contamination, groundwater is often a case of out of sight and out of mind, in spite of the fact that many groundwater sources have varying degrees of vulnerability to contamination by both pathogens and chemicals.

WHO provide an overview of the key steps in developing a WSP in the Guidelines as follows:

- Assemble the team to prepare the plan.
- Document and describe the system.
- Carry out hazard identification, understanding how and where hazards can gain entry to the supply, and risk assessment.
- Produce an assessment of the system with a description and flow diagram.
- Identify risk control measures.
- Define monitoring of control measures – the limits that define acceptable performance and how these are measured.
- Verify that the plan is working effectively.
- Develop supporting programmes including training and standard operating procedures.
- Prepare management procedures including corrective actions and emergency plans.
- Establish documentation and communication procedures.

By putting in place a water quality management system it is possible to minimise the risks of contamination without the need to massively increase monitoring for a wide range of potential contaminants. This, like HACCP, is a much more cost effective way of assuring the quality of a key raw ingredient that is also important in processing and agricultural production.

ANNEX 2

Framework for Assessing the Fitness for Purpose of Water in Food Production and Processing

Purpose for which water is required
Who or what exposed?

Does water stream have potential to contact product?

At what stage in production cycle is contact foreseen?

What are the receptors? Crop, livestock, human?

Nature of contact? Water, ice, steam.

Is there subsequent processing that would kill microorganisms?

Guidelines/regulations to demonstrate safety of finished product – food law and water guidelines

Existing mitigation steps
Intentional and unintentional

What happens now?

Type of irrigation?

Washing in potable water?

Existing treatment?

Subsequent processing step?

Source of Water and Potential Hazards

Raw water, natural and anthropogenic.

Deliberately added, disinfection.

Chemicals added to process water, chlorine, cleaning, manufacture.

Reaction products of disinfection.

Substances added to facilitate processing and substances extracted from 'food'.

Boiler water additives (leaks or non-potable steam).

Recycled water in food process.

Exposure and risk. How much?

Is exposure of product/consumer possible/likely?

If so, how much and how long?

Will it exceed a toxicologically significant level (notwithstanding analytical uncertainty)?

(Data, standards, TTC).

Above or below std,
no std TTC, above or below TTC.

Above or below value derived by risk characterisation.

Could viable pathogens be present and are the numbers sufficient to increase the risk of disease?

Additional mitigation measures

Avoid problem, prevent or reduce exposure.

If no mitigation possible and exposure unavoidable further risk characterisation.

Monitoring and verification

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ACRONYMS

ADI	Acceptable Daily Intake
ALARA	As low as reasonably achievable
ALARP	As low as reasonably practicable
AOP	Advanced oxidation processes
COD	Chemical oxygen demand
BOD	Biological oxygen demand
HACCP	Hazard analysis and critical control point
TDI	Tolerable Daily Intake
TTC	Threshold of toxicological concern
UV	Ultraviolet
WSP	Water safety plans

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