The project for sustainable water use in chemical, paper, textile and food industries

Methodology Water Quality Control
Identification and management of water quality aspects in an optimised water network based on HACCP methodology and principles

Authors: Henrik Grüttner, William Frank and Gert Holm Kristensen (DHI)
Supported by: L. Feenstra, W.G.J.M. van Tongeren (TNO)

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Executive summary

This report is a result of the project AquaFit4Use, a large-scale European research project co-financed by the 7th framework programme of the European Union on water treatment technologies and processes.

This report describes a method for establishing a quality control system for the total water system. The suggested approach is meant to be applied on water networks in industry – including one or more recycling schemes developed by the methodology described elsewhere in the Aqua-Fit-4-Use methodology.

The method described here uses the concept of the HACCP – in particular the approach of identification and use of Critical Control Points. Hence the principles of HACCP are briefly summarised as an introduction to the presentation of the suggested method.

The core approach of the suggested method is to assess the total water system by a step-by-step check of each use of alternative water qualities including recycled water for unforeseen impacts of the water due to unusual events at the source of the water.

The core of the suggested approach is the identification of Critical Control Points during the three steps outlined below:

Step:	Outcome:
1. Identification of all Potential Critical Control Points (PCCPs) taking the Water Quality Definition as the starting point - going backwards though the supply system.	List of PCCPs with indication of process / point of concern and components / limits in focus.
2. Assessment of each PCCP for its use as CCP according to the HACCP principles – in particularly assessment of existence of applicable control method.	List of CCPs with description of point of concern, components / limits in focus and method of control.
3. Describe for each CCP the way of control, the limits to be met and the corrective measures to be applied if unforeseen performance is found.	List of CCPs with description of control points and components and limit values, the surveillance/monitoring system and the corrective measures to be applied in case of deviations.

Examples of unusual events are listed and is it stressed that normal variations in the compositions of the recycled water should be included in the initial matching of the water flows.

A decision three for the identification and assessment of the critical control points is presented. The methodology can be used independent but also easily incorporated in existing HACCP based Quality management systems

Content

1 Introduction

This report is a result of the project AquaFit4Use, a large-scale European research project co-financed by the 7th framework programme of the European Union on water treatment technologies and processes.
The research objectives of AquaFit4Use are the development of new, reliable cost-effective technologies, tools and methods for sustainable water supply use and discharge in the main water using industries in Europe in order to reduce fresh water needs, mitigate environmental impact, produce and use water of a quality in accordance with the industries specifications (fit-for-use), leading to a further closure of water cycle.

For more information on AquaFit4Use, please visit the project website: www.aquafit4use.eu.

1.1 General

Any process in an industry must be considered for the need for quality control, including those using different qualities of water. Introduction of a water reuse scheme hence will create a need to adapt the quality control system to this situation.

When applying alternative water sources/qualities and establishing a water-recycling scheme – whatever it is inside an industry or between industries – one is introducing a risk due to the narrowing the safety margin between then required water quality for a given process and the quality of the supplied water. Handling that risk is necessary and probably also the single most important factor for overcoming the psychological barrier towards water recycling that still exists in many industries.

For example using fresh drinking water for washing soiled potatoes will definitely not possess a risk of contamination of the potatoes – but the moment we start recycling that water we accept a certain risk of accumulation of soil compounds in the water and hence we need to define the acceptable level for the potential problem substances in the water and define ways to control that risk.

The risk that the expected quality of the water sources will change from the defined depends on the likeliness that certain changes will occur. Such changes can occur over a short time span by unexpected changes in the supply process or over a longer time period due to gradual changes – e.g. accumulation of substances in the system.

Overall the aim of the water quality control system is to assure ourselves – and the relevant stakeholders – that the process is still under control – despite the fact that the safety margin may have been reduced.

Defining such safety margins is a complex task. For certain risks we will not accept any kind of risk. For example regarding pathogenic microorganisms in production of food or medicine we expect the supplier companies to operate with the biggest possible safety margin. While for other aspects like for example the concentrations of salt in a paper product has a much wider tolerance.

By supplying some processes with recycled water or water from alternative sources the industry introduces a controlled risk and takes over part of the responsibility for water quality control originally being part of the external water supplier.

Quality control systems have been developed and implemented in most braches of industry but in particular the food industry has developed concepts for management and control of potential risks originating from microbiological contamination. The most important tool developed for this purpose is the Hazard Assessment and Critical Control Point (HACCP) methodology.
The principles of this methodology has proven useful for other purposes and hence it has been decided to seek to develop methodology for quality control related to water recycling / reuse in industry based on these principles.

This material will not be summarised here but rather we refer to excellent reports like the report prepared by International Life Sciences Institute: Considering Water Quality for Use in the Food Industry (ILSI, 2008).

1.2 Objectives of this note report

This report describes the basic approach and principles for Water Quality Control (WQC) by adopting and application of the HACCP principles for the water systems with particular focus on the identification and description of Critical Control Points.

Water Quality Control (WQC) methodology is a structured method for identification of points of control in industrial processes and other industrial water use. With the help of the WQC Methodology, water managers, quality managers and other persons in industries, responsible for processes, products and the environment can establish a system that secures appropriate control.

The WQC methodology is part of the total Water Quality Management structure (WQM) as shown in the picture below. Besides WQC also Water Quality Definition (WQD) is part of WQM.
WQM is the basis for sustainable water use in industry. For good water quality management two aspects are of main importance:

1. To define the water quality demands
2. To guarantee the production and control of this quality

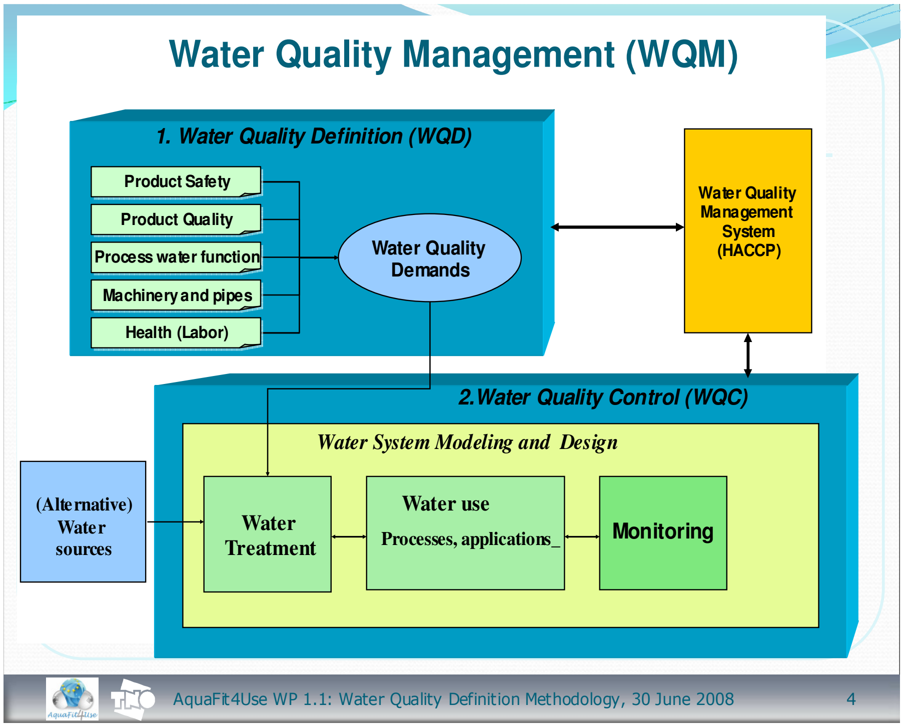

Figure 1 Overview Water Quality Management

The methodology of WQC structures the assessment of the different quality concerns like product safety, product quality and process equipment (machinery) in relation to the application of the different water qualities defined by the WQD method.

Water Quality Control is a task in the first work package of Sub-project 1 (SP 1) of AquaFit4Use Water Quality Definition and Control.
WP 1.1. is focused on the development of a Water Quality Definition methodology, with supporting tools for selecting relevant information and Water Quality Control.
In WP 1.2. real data will be gathered for different applications (parameters). Water quality parameters related to generic problems like scaling, fouling and corrosion will be gathered, and also specific parameters related to processes. Besides technical demands, also attention will be paid to demands related to environment, safety and health. The data of WP 1.2 will be used to fill in the Water Quality Library of the Water Quality Management WQM software tool, which will be developed in WP 1.3.

The WQC methodology can be regarded as one of the modules which will be used in the WQM-tool, see picture below:

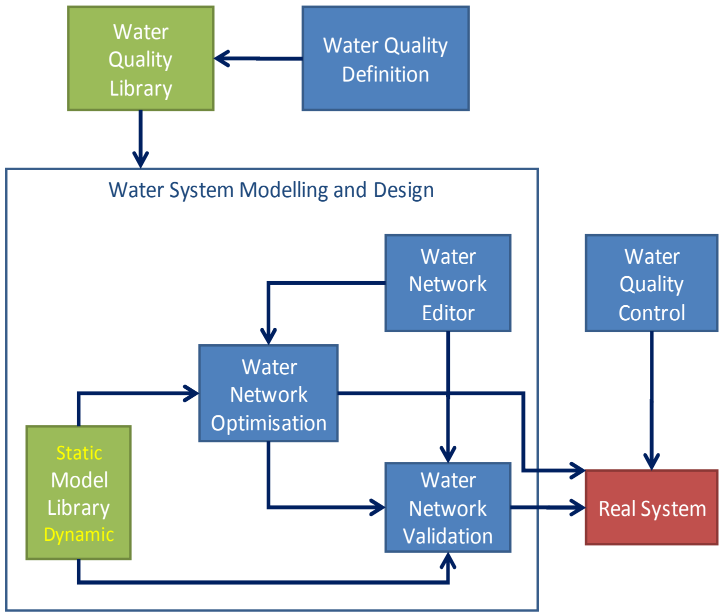

Figure 2 Water Quality Management Tool

The objective of this report is to support the development of a standard methodology for the assessment of a water system, including water treatment, monitoring and guarantee as part of the overall Water Quality Management (WQM) tool.

The report is structured with in three parts:

- An general introduction to the principles of Hazard Analysis Critical Control Point System (the HACCP system) which is to be considered the theoretical backbone of the described approach (section 2)
- A description of how the approach and principles of HACCP can be applied on water systems by extension of some of the definitions and considering the different water qualities as the a product (section 3), and finally
- A brief summing up of the approach (section 4).

2 The Hazard Analysis Critical Control Point System

2.1 General introduction

This section summarizes the general principles of the HACCP approach as a background for the more detailed assessment of the application of this methodology for water recycling / reuse found in section 3.

HACCP is a safety management tool, and it is based on the recognition that hazardous events may happen at different points during production. This system aims to identify problems before they occur, and establish measures for their control at the stages in production that are critical.

The HACCP concept is a systematic approach accepted in food control, and it can be used to control and take care of a better safety and quality in water systems as well (Vanne *et al.*, 1996).

HACCP can be incorporated into TQM programmes for the following reasons:

- To improve the efficacy of the operations and the quality of the products
- To ensure food (product) safety
- To satisfy a requirement from the customers or purchasers
- To prove a due diligence defence in legal actions
- To keep up with their competitors

These management philosophies, TQM and HACCP, can be implemented together to produce safe, high quality foods, while keeping manufacturing costs reasonable (NFPA, 1992). However, it should be taken into account that HACCP is within this frame work totally focused on product safety and not on quality.

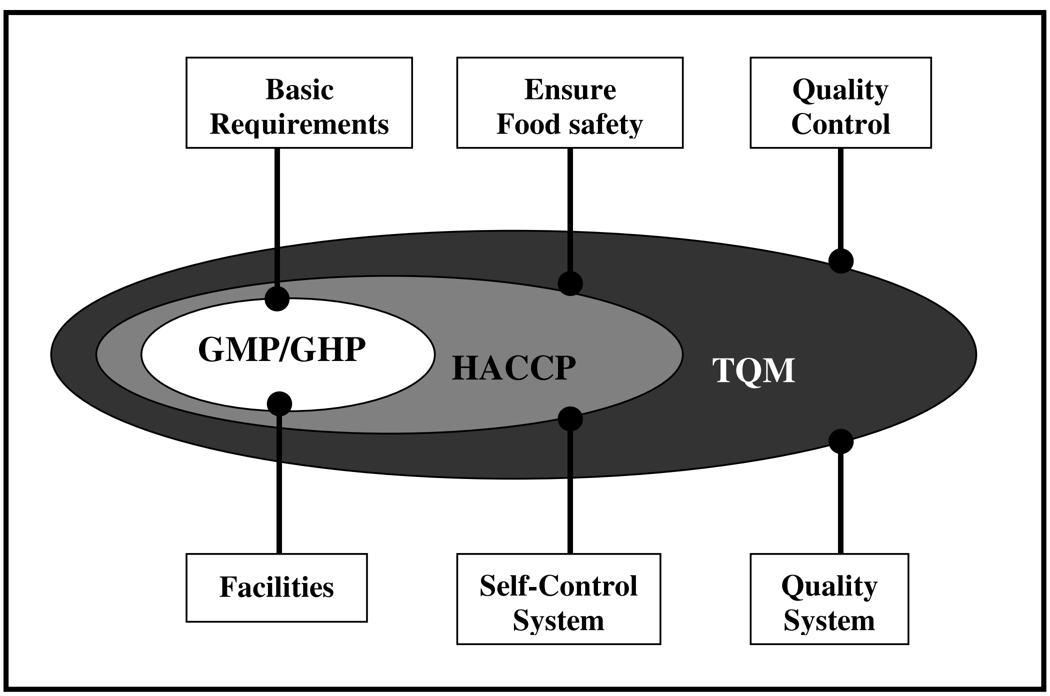

Figure 3 Interdependence between various quality and safety systems (adapted from Jouve, 1998)

The HACCP system minimizes microbiological, chemical and physical hazards by anticipation and prevention before and during processing or handling operations, rather than inspection (NFPA, 1992), eliminating virtually the need for finished product testing (Jouve, 1994). This takes place by identifying the safety risks inherent in the product and devising preventive measures, which can be monitored in order to control the process.

2.2 Principles of HACCP

The principles of HACCP, its preliminary steps, its seven steps, and its application and implementation have been described in detail in a number of publications and guidelines (e.g.: ICMSF, 1988; NACMCF, 1992; Codex, 1993; Huss, 1994; NFPA, 1993; Notermans et al., 1994a; Notermans et al., 1994b; WHO/FAO, 1995; USDA, 1999; Casani et al., 2005).

A HACCP system will be better developed if some preliminary steps are taken (NFPA, 1993; USDA, 1999). and these are:

1. Define scope of study
2. Select a HACCP team
3. Describe the types of products, its method of production and distribution
4. Describe the intended use and the consumers of the product
5. Develop a flow diagram including all the steps involved in the production
6. Perform on-site verification. This step is a key in finalizing process flow diagrams, and it should be performed very carefully by walking through the plant and making sure that all the steps in the process are included

Once these preliminary steps have been completed, the seven main elements of HACCP are applied. In principle these seven elements should be considered for every potential hazard, but in practice one will normally assess the hazards together in an integral operation.

The principles of HACCP and its seven main elements (Figure 4), as set out by the Codex Alimentarius Commission, are (Codex, 1991):

1. **Hazard analysis**: identification of potentially biological, chemical and physical hazards associated at all stages of production up to the point of consumption. Microbiological hazards are defined as the unacceptable contamination, growth or survival of microorganisms that may affect safety or quality or the unacceptable production or persistence of substances such as toxins, enzymes or products of microbial metabolism. The steps that follow must include an assessment of the hazards (severity and risk) associated with each organism / chemical property of the water and the probability of their occurrence. This aspect will be further developed in section 3.

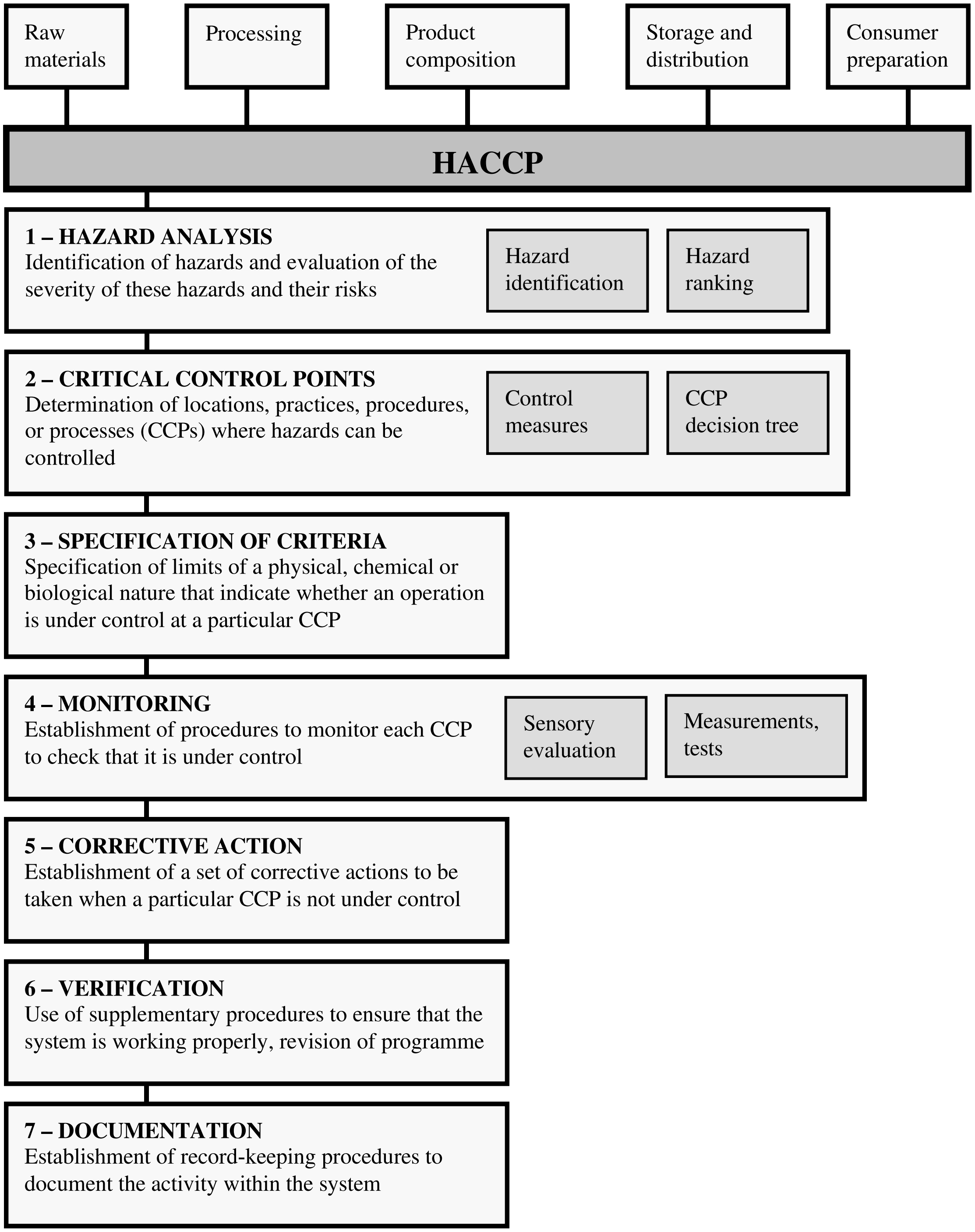

Figure 4 The seven main elements in the Hazard Analysis Critical Control Point

(ICMSF, 1988; NACMCF, 1992; Huss, 1994; Notermans et al., 1994a; Notermans et al., 1994b)

2. Determination of **Critical Control Points** (CCPs)**.** CCPs are points in the process (location, procedure or processing step) where loss of control has a reasonable probability of creating an unacceptable risk. These control steps are determined in order to prevent, eliminate or minimize the hazards. When a critical limit at a CCP is violated, the process must be stopped and the problem corrected.

   The number of CCPs depends on the complexity and the nature of the process and the product, and using a decision tree (Figure 5) will avoid unnecessary duplication of CCPs but should ensure adequate control.

Answer each question in sequence

Q1. Do preventive measure(s) exist for the identified hazard?

YES → Q2

NO → Modify step, process or product (→ Q1)

NO → Is control at this step necessary?

Is control at this step necessary? → YES → Modify step, process or product

Is control at this step necessary? → NO → NOT a CCP → STOP*

Q2. Does this step eliminate or reduce the likely occurrence of a hazard to an acceptable value?

YES → CRITICAL CONTROL POINT

NO → Q3

Q3. Could contamination with identified hazard(s) occur in excess of acceptable level(s) or could these increase to unacceptable levels?

YES → Q4

NO → NOT a CCP → STOP*

Q4. Will a subsequent step eliminate identified hazard(s) or reduce the likely occurrence to and acceptable level?

NO → **CRITICAL CONTROL POINT**

YES → NOT a CCP → STOP*

*Proceed to next step in the described process

Figure 5 CCP Decision tree (NFPA, 1993). The practical use of this decision tree in relation to quality control in industrial water networks is elaborated in section 3.

3. **Specification or establishment of criteria** that must be met to ensure that CCPs are under control. A detailed description of all CCPs, including determination of criteria and specified limits or characteristics, which ensure that a product is safe and of acceptable quality, is necessary.

4. Establishment or implementation of a **monitoring system** for each CCP. The monitoring should measure accurately the chosen factors, which control a CCP. (Please note that 'monitoring' is here in the management meaning of the word.)

5. Establishment of **corrective actions** when CCPs are not under control. The system must allow for corrective action to be taken immediately when the monitoring results indicate that a particular CCP is not under control, and this may be taken before deviation leads to a safety hazard.

6. Establishment of procedures for **verification**. Random sampling and analysis can be used as supplementary information to check whether the HACCP system is working properly.

7. Establishment of **documentation** and record keeping. The approved HACCP-plan and associated records must be on file. Documentation of HACCP procedures at all steps is essential and it should be clear at all times who is responsible for keeping the records.

It is important to realise that these elements must be seen as an integral system and the realisation might not be a step-by-step procedure but rather an integrated process.

3 The use of the HACCP approach on water networks

3.1 Introduction

The key approach to managing and controlling the potential hazards in water networks is to consider the water as an internal 'product' delivered and hence some obvious similarities to the general application of the HACCP-approach arise, but also a number of deviations arise due to the many factors to be considered when dealing with water as the product. Hence, using the HACCP principles in relation to water networks requires some modifications in the definitions and use of the concepts in order to cover the broader scope of potential hazards and risks.

During the Water Quality Definition[1] the actual potential hazards are identified and transferred into water quality components of concern. In that way this activity partly covers the first element of the HACCP approach – 'the hazard analysis' – by identification of the components to be aware of and the 'secure' concentration level.
What is lacking in the water quality definition is the assessment of the probability and consequences of violations of the criteria, and this is what we call risk assessment in this context.

Below the different steps in applying the HACCP-methodology to a water network is described with emphasis on the aspects particularly important for 'the water issue'.

The description covers the HACCP-elements:

- **Hazard analysis and risk assessment**

- **Identification of critical control points**. In this context this is divided into two steps:
  - Identification of Potential Critical Control Points
  - Determining Critical Control Points

- **Specification of the criteria** for the Critical Control Points identified *including* considerations regarding **corrective actions** and finally

- Establishing of a surveillance / monitoring system

For procedures on **verification** and **documentation** please refer to general literature regarding quality control.

3.2 Definitions of terms (for reference)

The terms used within the HACCP need to be defined before consideration is given to the way the system may be applied (NACMCF, 1992; Notermans and Teunis, 1996). In this context some of the terms have an extended scope compared to the more traditional HACCP systems:

Hazards: A hazard is the potential consequence of exceeding of a water quality limit, in particular with respects to product safety or quality, process performance, equipment, or workers health and safety or environment.

Risk: An estimate of the probability of an adverse effect – the hazards – on products, production equipment or employees.

Risk factor: The component / parameter that may cause a problem.

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[1] AquaFit4Use internal result no. 1.1.1.1: Basic Structure Water Quality Definition, May 2009

Controlling activity: The activity required to keep the risk factor under control.

Risk assessment: Assessment of the likelihood of the risk and the consequence of the risk.

Point of control: The point where we can do something to keep the actual risk factor under control. Whether this will end up being a Critical Control Point depends on the risk assessment.

PCCP / **Potential Critical Control Point**: An intermediate identification of matters that need concern. To be transformed into a real CCP, a monitoring point or rejected.

CCP / **Critical Control Point:** A point in the water network (originally in the entire production lay-out) that need routine control in order to manage the identified risks.

Control point: A point in the system where the level of a component / parameter is controlled with regular intervals.

HACCP plan: The written document which is based upon the principles of HACCP, and which delineates the procedures to be followed to assure the control of a specific process or procedure.

HACCP system: The result of the implementation of the HACCP plan.

3.3 Hazard analysis and risk assessment

As explained in the AquaFit4Use report regarding Water Quality Definition[2] the way to identify the quality aspects and required water quality is to address the five key concerns:

- Product safety
- Product quality
- Process water function
- Equipment, machinery and pipes
- Health and working conditions

In this way the potential hazard routes has already been identified together with the acceptable concentration levels of the relevant components. Hence it is obvious that the Water Quality Definition must be the starting point for hazard assessment.

Basically all cases of unforeseen exceeding of the water quality definition (WQD) represent a potential risk to the process receiving the actual water stream, but naturally all violations will not be equally serious.

The risk assessment of exceeding the determined Water Quality Definition must focus on two aspects:

1) An assessment of the seriousness/consequence/impacts of this deviation from the planned situation determined by the Water Quality Definition

2) An assessment of the probability/likelihood that the actual water quality will exceed the criteria in the Water Quality Definition (considering also possible safety margin)

[2] AquaFit4Use internal result no. 1.1.1.1: Basic Structure Water Quality Definition, May 2009

These two aspects will be considered below and finally a model for a combined approach is presented.

Possible disturbances and their consequences

The possible disturbances in the system might be related to:

- **Unforeseen variations** in the water source process – perhaps related to process problems in the process supplying the water
- **Contamination** of the water source related to leakages in chemical dosing systems leakages in pump sealing etc.
- **Insufficient treatment** / cleaning of the source water – perhaps related to failures in the treatment system e.g. breakthroughs in filters
- **Unforeseen impacts of water storage and transportation** – e.g. microbial growth in the system or unforeseen corrosion.

Annex 1 provides a more detailed list of potential disturbances of a water system and selected water treatment technologies.

The consequences of these disturbances will depend on the nature of the substances involved and each company must do its own assessment of the potential hazards (- preferably as part of the Water Quality Definition).

In Table 1 a theoretical hazard assessment for a food industry has been performed with focus on water. The assessment has been performed for four groups of compound found in the water due to the different nature of these four groups.

- Physical properties of the water – mainly temperature
- Chemical properties of the water – like pH, content of dissolved salts or organic matter
- Micro-pollutants like heavy metals or specific organic
- Microbiological components – like e.g. *Legionella spp.*

Table 1 A theoretical hazard assessment for a food industry for the four groups of compounds relevant for a Water Quality Control Scheme

	Physical properties	**Major chemical properties**	**Micro-pollutants**	**Microbial components**
Examples	Temperature	pH, dissolved salts, organic matter	Heavy metals, specific organic compounds	Microbial species like Legionella spp. or mould spores
Product safety	Too low temperature might provide insufficient thermal disinfection allowing growth of pathogens – potentially making the customers ill ***(Acute effects on humans)***	These compounds will typically impact product quality – see below. Certain chemicals might be toxic in higher concentrations ***(Acute effects on humans)***	For bio-accumulating substances higher concentrations might lead to increased burden on humans consuming the food ***(Long term effects on humans)***	Typically microbial components are controlled by temperature (see that) or by other means, but a higher load might exceed the capacities of the disinfections system ***(Acute effects on humans)***
Product quality	Too low temperature might provide insufficient thermal disinfection allowing growth of microorganisms that destroys the products / reduces	Deviating pH or contamination with salts or organic matter might impact the product quality (taste / smell) or reduce the product life-time	Higher concentrations might be considered a contamination of the food – due to the increased burden on the humans consuming the food	Typically microbial components are controlled by temperature (see that) or by other means, but a higher load will mean more difficulties to control

	Physical properties	Major chemical properties	Micro-pollutants	Microbial components
	the life-time of the product ***(Economic impacts)***	***(Economic impacts)***	– leading to negative recognition of the product ***(Economic impacts)***	***(Economic impacts)***
Process water function	Too low / too high temperature might impact the ability of the water to dissolve specific ingredients or additives (impacting product quality – see above) Water temperatures might also impact the cleaning properties (impacting product safety – see above)	Deviating pH might impact the ability of the water to dissolve specific ingredients or additives (impacting product quality – see above)	Certain micro-pollutants might be seen as contaminants making the water unsuitable for cleaning ***(Economic impacts)***	A microbial contamination of the water might make it unsuitable for certain purposes, in particular use in products or cleaning ***(Economic impacts)***
Equipment	Too high water temperature might impact lifetime of equipment due to increased corrosion or reduced lifetime of sealing rings etc. ***(Economic impacts)***	Deviating pH might impact lifetime of equipment due to increased corrosion or reduced lifetime of sealing rings etc. ***(Economic impacts)***	Due to very low concentrations micro-pollutants will typically not have an impacts on the equipment	Uncontrolled build-up of micro-organisms might lead to increased corrosion or malfunction ***(Economic impacts)***
Health and safety (working conditions)	Deviating temperatures might create accidents (acute effects on humans)	Contamination with dissolved organic matter might create a basis for growth of microorganisms (like Legionella) and in that way create a risk for illness of workers ***(Acute impacts on humans)***	Due to very low concentrations micro-pollutants will typically not have an impacts on the working condition	Uncontrolled build-up of micro-organisms might generate toxic impacts (illness) on the workers due to the liberation of endo-toxins or similar effects ***(Acute impacts on humans)***

As indicated in the table the potential impacts and hazards for the four groups are quite different with respect to the possible chain of problems.

Overall the hazards can be sorted out in different categories:

- Potential ***acute effects on humans*** in particular inducing illness or toxic effect
- Potential ***long term impacts on humans*** due to increased burden of micro-pollutants with negative effects (in particular relevant for heavy metals and specific organic micro-pollutants – persistent organic contaminants)
- Potential ***economic impacts*** in particular due to product quality problems giving impacts in the market of the product or due to less efficient production

It must be stressed that such an assessment of the potential hazards will depend on the nature of the production and is very hard to generalise. A responsible company will have to do the assessment themselves and determine a policy for the acceptable level of risk or level of safety required for the identified hazards. For this the above categorisation of hazards might be relevant to consider.

Possible means of control

The main aim of establishing a Water Quality Control Scheme is to be in control of the different potential risks by establishing a set of relevant points of control with defined corrective measures.

Table 2 gives some overall quality control considerations for the four groups of compounds mentioned above (- with reference to the example shown in Table 1).

Table 2 Overall quality control considerations for the four groups of compounds

	Physical properties	**Major chemical properties**	**Micro pollutants**	**Microbial components**
Impacted by	Storage Mixing	1. The upstream processes supplying the water 2. Leaking dosage equipment 3. Insufficient effects of integrated water treatment devises (e.g. softening units)	Supply of water Pre-treatment of the water (filtering, softening etc. might contaminate the water) Piping and handling equipment	Supply of water Storage (time, temperature and content of organic matter and nutrients) Design of equipment (must be easy to clean)
Adjusted / controlled by	Heating / cooling devises	1. Upstream processes 2. Dosing equipment 3. Integrated water treatment	The supply The pre-treatment process and equipment	The supply The storage conditions
Generally recommended point of process control	The point of supply to the actual process	The point of supply to the actual process	The supply water after pre-treatment	The supply water after pre-treatment The point of supply to the actual process
Alternative indirect points of control	The function of the heating / cooling devises	1. Process control of upstream processes 2. Preventive maintenance of dosing equipment 3. Surveillance and monitoring of integrated treatment	Selection of less contaminating pre-treatment process and/or equipment	The storage conditions – including frequency and efficiency of cleaning)

As illustrated the points of control differ significantly for the four groups of compounds but again the assessment must be done for the specific situation and the presentation in Table 2 should only be seen as an illustrative example.

Determining the normal level of variations

During the mapping operation of a process the 'normal level of variations' should be determined for each relevant parameter and it should be determined what to use in the modelling of possible water recycling options; should it be the mean, the average, the maximum value identified or the 90% percentile – just to mention some option.

Figure 6 illustrates the outcome of a mapping situation and the corresponding frequency distribution. For this example the statistical mean value is 10.7 the average is 11.2, the standard deviation 3.0 and the maximum is 17.5.

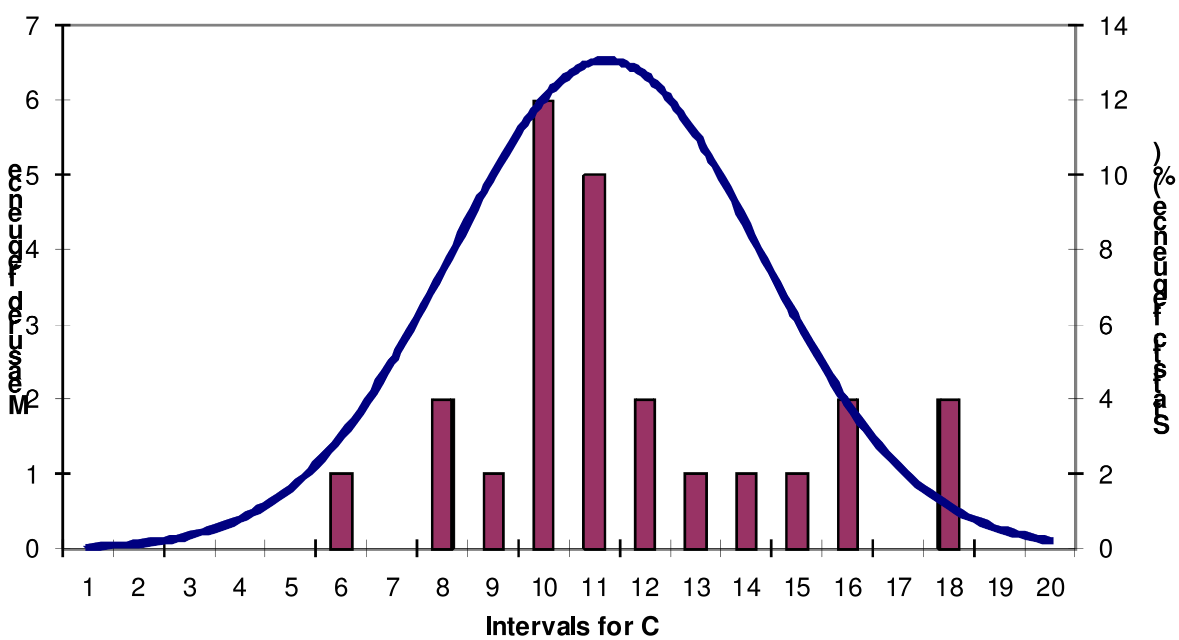


Figure 6 An illustration of the outcome of a mapping situation and the corresponding frequency distribution.

Safety margins – a basic tool for handling the risks

A way to handle the potential hazards and risks is to express the quality policy in the form of safety margins. Such safety margins might be fixed differently for the different hazards. For example the risks might be sorted out according to the overall hazards identified above and a high safety factor applied for the potential acute impacts on humans, lower for the potential long term impacts and lowest for the potential economic impacts (see also 'Combined approach' below).

The Water Quality Management System provides an opportunity to manage this by making the determined safety margins visible as a distance between the mapped water composition for a specific parameter and the Water Quality Definition for the same parameter. Ideally this safety factor should be visible as a specific parameter in the WQMS but in the present version this feature is not available and hence the safety margins must be included in the Water Quality Definition. It is recommended to keep track of the included safety margins in order to be able to change the factors and to be able to communicate these safety margins to potential stakeholders like authorities and customers.

Safety margins typically fix an order of magnitudes between the quality requirements of a certain process – the Water Quality Definition – and the quality of the water potentially supplied to the process. Consequently the determinations of the safety margins must theoretically also consider the mapping method as mentioned above. In practice this might mean less if the safety margin is fixed as log 3 or 4 if the normal variation is within one log unit, but if the normal variations is bigger or the safety margin smaller if might become more important.

Setting the level of control / surveillance
The other main factor in the risk assessment is the probability that a certain disturbance will occur. Naturally this is hard to determine empirically so basically it will be a theoretical consideration. Some empiric information might be collected by interviewing experienced production workers but this applies mainly to the existing situations, naturally they will not be able to judge about a new system. This is one of the reasons why the quality control system has to have a build in scheme of revision where the 'levels of surveillance' – including frequencies and type of control – is considered.

Setting the levels of surveillance of each individual control point should be done with a reference to the nature of the critical parameters and potential effects of the identified hazards. Again this is hard to generalise but it might be relevant to distinguish between different levels / approaches:

- For potentially **acute effects** naturally **intensive surveillance** is needed

- While **long term effects** requires some kind of **statistical control** – often referred to as 'monitoring'

In the traditional application of the HACCP approach for food hygiene control the potential hazard will always be acute in its nature, but expanding the application to other concerns will mean that some of the hazards will have a more long term nature and hence is becomes relevant to consider monitoring with different form of sampling and analysis. It is not within the scope of this report to describe the relevant analytical techniques available for the different compounds for that we refer to the abundant available literature.

On-line monitoring might be a relevant option for surveillance of selected compounds measured either directly or indirectly. Annex 2 provides an indicative list of options including some examples of indirect measuring like e.g. measuring the level of bacteria by the use of turbidity.

From a quality control point of view it is important to stress that on-line monitors can provide 'fake safety' if routines for frequent control and calibration of the devises are not established. So generally such devises should be reserved for situations where intensive surveillance is required also due to the cost which might be significant.

A combined approach
Several aspects of Water Quality Control have been discussed in this section and naturally it is up to each company to combine as they see fit. Table 3 below illustrates how these aspects might be combined for the five main concerns of the Water Quality Definition.

Table 3 A possible approach considering the five different concerns of the water quality definition

	Seriousness of potential hazards *Type of effect*	Safety margin **Recommended surveillance**
Product safety	**Very high** - due to the potential impacts on humans *Acute effects*	Safety margin: log 3 **Intensive surveillance**
Product quality	**High** - due to the potential economic impacts of bad product quality *Acute effects*	Safety margin: log 2 **Intensive surveillance**
Process water function	**High** - due to the potential malfunction of the process *Acute effects*	Safety margin: log 2 **Statistical surveillance**
Equipment, machinery and pipes	**Low** – due to possibility to correct *Long term effects*	Safety margin: log 1 **Statistical surveillance**
Health and working conditions	**Very high** - due to the potential impacts on humans *Acute effects*	Safety margin: log 3 **Intensive surveillance**

Categorizing the risk assessment

A way to combine the two main factors of the risk assessment – the seriousness and the probability – can be to categorize by use of a colour coding as illustrated in Figure 7.

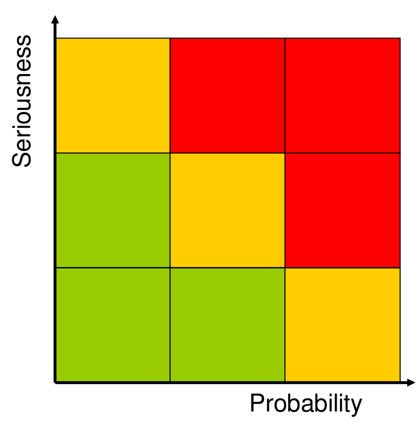


Figure 7 Conceptual diagram illustrating the combined assessment of probability and seriousness of a certain risk.

- A high probability and a high seriousness / consequence will mean a need for intense control meaning that there is probably a need for a Critical Control Point (Indicated by red).
- A medium probability and a medium seriousness / consequence will mean a need for some kind of control but perhaps not as a Critical Control Point (Indicated by yellow).

- High seriousness in combination with low probability is also indicated by yellow since the low probability will indicate a limited need for control.

- Low seriousness combined with high probability will indicate that this is not something that needs 'intensive surveillance' but rather needs considerations about way to reduce the probability.

- A low probability and a low seriousness naturally will mean that control is not needed (Indicated by green).

This approach is further illustrated for the case presented in annex 3 and 4.

3.4 Identification of Potential Critical Control Points

As described the HACCP methodology works with Critical Control Points as a key element to manage the potential risks and be in control of unforeseen disturbances. This approach is adopted here but as described above the concerns and potential hazards has to be extended when all aspects of applying water recycling schemes or alternative water sources are considered.

Generally the approach for identification of Critical Control Points is to identify the point where a reasonable level of surveillance can support you in being in control of the process.

To identify such points for the relevant water parameters (risk factors) it is recommended to track backwards (upstream) in the water flow from the actual process to the point where the actual water quality component is potentially impacted.

The list of components and the actual critical levels of each components are developed as part of the Water Quality Definition (WQD), so in fact the WQD must act as the starting point in the analysis.

Hence the recommended approach is for each identified component (and the related limit value) move backwards in the water network and identify the point where this water aspect is controlled / impacted - the Potential Critical Control Points (PCCP).

All processes impacting the water composition in an unforeseen way are in principles PCCPs.

That might include:
- The process supplying the water – the 'source' process
- Any integrated water treatment process
- The pumping, handling or storage of the water
- Any other risk of contamination / pollution of the supply water for the actual process

It is difficult to generalise the impacts of the source processes, but in many cases **mass balance considerations** might be useful – for example the assess for possible failures or mistakes that might happen in the dosing or use of the chemicals in the process.

For any integrated water treatment processes the attention should be on **possible failures** of those systems and possible means to control good/normal performance. In many cases identification of indirect performance measures might be useful to identify the most relevant control points: Please refer to annex 1 for more details.

The **handling and storage** of the water opens a whole new series of possible critical points related to many of the components. Physical, chemical and microbiological conditions of the water might change as a consequence of storage. Generally in the identification of critical control points it should be emphasised that the storage is kept within the limits originally determined for the water network and that the emptying and cleaning procedures are maintained.

Other potential risks of contamination might include **mistakes in operation** of the system, **contamination from leaking pump sealants, leaking valves** etc.

The identification of PCCPs can in principle be done automatically for selected water networks if it is possible to identify an algorithm that goes backward in the water supply of each process for each component and determines where the actual component is impacted (and hence should be assessed for the need for control). An attempt to illustrate a simplified algorithm is found in section 4.

3.5 Determining Critical Control Points

The identified PCCP's needs further assessment for their use as Critical Control Points (CCPs). Please also consult figure 2.3 for this assessment.

As mentioned the definition of a Critical Control Point is a point in the water network that need routine control/surveillance in order to manage the potential risks – **in order to be in control**.

Hence a CCP can be of different nature:

a) It may be a **manual procedure** applied frequently for checking / controlling something.

b) It might be a point where certain **water quality components are controlled directly** for example in the form of a specific on-line monitoring of a water quality component.

c) Or it might be a point where the **correct performance of a unit is controlled indirectly** for example by surveillance of the electricity consumption or by a pressure difference.

Sampling and chemicals analysis of selected components indicating if the water quality monitored regularly against certain predefined values (PCCP1 in the example above) is generally not considered a Critical Control Point but rather as a Monitoring Point.

For each critical control **a certain corrective action is defined** if the predefined values are exceeded, and again these actions can be of different nature according to the actual situation. Please refer to the case presented below for inspiration.

Assessment of probability

As explained above the fixing of CCPs should include an assessment of the probability that the actual water quality may exceed the requirement in the WQD. This of course will depend – among other things – on the distance between the actual water quality and defined criteria (the applied safety margin). Hence the assessment should include such considerations.

Further the variations of the actual water quality should be considered since those variations might periodically reduce the distance between the actual water quality and the defined criteria[3].

[3] Actually the assessment of the variations of the actual water quality should be considered already during the mapping of the flows and the variance should be defined.

Finally the supply process should be assessed for all the potential impacts / problems mentioned above in section 3.3 and the likeliness that the mentioned disturbances happen should be assessed.

This whole assessment is illustrated with an example below.

3.6 An example for illustration of the suggested approach

Below an example is provided to illustrate the methodology for identification of PCCPs and CCPs.

To illustrate the process for identification of the potential critical control points a typical water supply situation (it might be a textile dyeing industry) is assessed.

The description takes the details of the water quality definition as the starting point to illustrate the intimate connection between the water quality definition and the identification of potential critical control points.

It is assumed in this situation that the relevant safety margins have already been applied in the determination of the actual concentration levels.

It must be stressed that the values are partly hypothetical and the list of parameters reduced in order to simplify the case.

Table 4 The Water Quality Definition for a hypothetical water supply situation

Components / Parameters	**Unit**	**Product Safety**	**Product Quality**	**Process Water Function**	**Machines & Pipes**	**Health & Working Conditions**	Combined
Conductivity	µS/cm			< 100	< 500		< 100
Hardness	ppm CaCO3			< 10	< 100		< 10
Colour	ppm		< 30				<30
COD	ppm			< 50			< 50
Cadmium	ppb	< 1					< 1
Chromium	ppb	< 0,5					< 0,5
Bacteria	CFU/100 ml					< 100	< 100
Legionella spp.	CFU/100 ml					ND	ND

ND = Not detectable

As seen from Table 4 the concern for **Product Safety** relates to heavy metals cadmium and chromium. The content of these components are determined mainly by the source of the water. Hence one PCCP will be the supply of fresh water.

The key aspect related to **Product Quality** is the colour of the water. This again is assumed to be determined by the supply and treatment of the fresh water. Hence it is needed to add this component to the PCCP identified for supply and treatment of fresh water.

The **Process Water Function** relates to the organic matter (COD) plus conductivity and hardness. The content of COD is determined by the water supply, while the conductivity is controlled by the softening process (the ionic exchanger). Hence it is needed to add the parameter COD to the control point for water supply and establish a new PCCP for the softening unit.

For the aspect **Machines and Pipes** the concern is again related to conductivity and hardness, but the values are above the values for the process water function and hence no new control is needed.

In relation to the **Health and Safety** aspect the components in focus is the microorganisms originating from the supply and treatment of fresh water but potentially also impacted by the conditions for storage and handling of the water – indicating a need to add components for hygienic control to the PCCP of the water immediately prior to the application in the process.

Summing up for this case three PCCPs are identified:

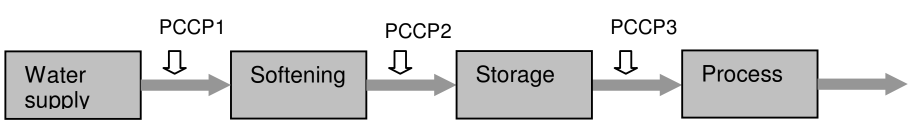
- PCCP1: The supply of fresh water
- PCCP2: The water softening unit
- PCCP3: The hygienic properties of the water delivered to the machines

In the table below these potential critical controls are listed with the values of concern.

Table 5 Potential Critical Control Points for the supply of water for the textile dyehouse

Components / Parameters	**Unit**	**PCCP1**	**PCCP2**	**PCCP3**
Point of control		Water supply	Softening of the water	Hygienic properties of the water
Conductivity	µS/cm		< 500	
Hardness	ppm CaCO3		< 100	
Colour	ppm	< 30		
COD	ppm	< 50		
Cadmium	ppb	< 1		
Chromium	ppb	< 0,5		
Bacteria	CFU/100 ml			< 100
Legionella	CFU/100 ml			ND

In other words the PCCPs relates to three different supply processes – depending on the component:



The next key questions will be:
Can the company actually control the composition of the actual water flow?
What is the probability that some unforeseen change will happen?
What will be the consequence of unforeseen changes making the water quality exceed the WQD?

For PCCP1 – the water supply:
Can the company control the composition?
No, they can only monitor.
Probability / consequence of exceeding the WQD:
The water quality control (monitoring) is done by the water supply company delivering the water. The company receiving the water can check the values on a specific web-page and the values are always well below defined values in the WQD. Hence it is concluded that for this PCCP the probability of exceeding the WQD values are very low. Further the consequences of exceeding the limit values are very limited except for the colour, but again this is very unlikely to happen.
Conclusion:
Hence the company concludes that this is not a CCP but they have to establish a procedure to secure regular checking the information from the water supply company.

For PCCP2 – the water softening:
Can the company control the composition?
Yes, the effect of the applied treatment can of course be controlled.
In this case the treatment applied is an ionic exchanger. For this devise it is known that the proper operation is controlled in the daily operation by regular regeneration of the resins and in the longer (maintenance) perspective by checking the capacity of the resins.

Probability / consequence of exceeding the WQD:
Malfunctioning of the ionic exchanger will immediately cause exceeding the limit values of the WQD and this will have serious consequences for the dyeing – in particular for the prewash of the textiles since the detergents will not work properly.
Conclusion:
It is concluded to transfer PCCP2 into two control points for the ionic exchanger treatment:
- A critical control point (CCP1) controlling that regeneration of the resins are done regularly with sufficiently short intervals and
- A control point (CP) controlling the efficiency/capacity of the resins by weekly analysis of the resulting water quality.

For PCCP3 – the hygienic quality after storage of the water:
Can the company control the composition?
Yes, to some extent they can control by regular emptying the storage tank to prevent formation of slime and sludge in the tank, and perhaps cleaning / disinfection of the tank.
Probability / consequence of exceeding the WQD:
The requirement for bacteria is not seen as a problem since the level found is normally well below the limit value in the WQD, and the consequence is very limited due to the fact that the water is heated to 90C in the dyeing machines.
But since they have seen positive testing for Legionella spp. from time to time – in particular in the summer periods – and since this potentially may harm the employees – it is considered a severe risk.
Conclusion:
It is concluded to transfer PCCP3 into a control point and a CCP for the water storage:
- A control point with a procedure stating that the tank must be emptied every Friday afternoon, and
- A critical control point (CCP2) for sampling for bacteria and Legionella every Friday before emptying the tank in order to assure that the procedure is sufficiently efficient.
If not the corrective action is cleaning of the tank with a disinfectant.

As illustrated by the example above a very important part of the definition of the CCPs is to identify how the actual water quality can be kept under control by different means. The example is further summarized in the Annex 3 and 4 as proposed sheets for CCP Identification and as a CCP Plan[4].

3.7 Specification of criteria and defining the monitoring system

For each critical control point it is recommended to register:

- The risk factors (the water quality components)
- The point of control (explained as detailed as possible)
- The controlling method
- The critical limits (the water quality definition values – perhaps ‘translated’ into another component)
- The surveillance procedure, frequency and responsibility
- The corrective measures stating the procedure and responsibility

A proposed sheet for such registrations – the CCP plan – is shown in Annex 4 with reference to the example above[5].

The **risk factors** and the **critical limits** are defined during the water quality definition process but in some cases it might be relevant to redefine the criteria into parameters that can give more immediate responses. Annex 1 provides some examples of how the different aspects can be controlled continuous and non-continuous methods. The list is not complete and should be seen as a indicate list for inspiration.

The **point of control** is typically defined during the assessment of the potential critical control points as described in the example.

The **controlling method** is given either by the actual component of concern or by the selected indirect control method identified in the assessment of the potential critical control points. Selection of alternative control methods for a certain risk factor should be done with great carefulness since the scope and specificity of the different methods might differ slightly and such differences might have unintended effects.

The selection of the **surveillance procedure** for each CCP naturally will depend on the nature of the CCP as mentioned in section 3.4. In any case it is needed to determine the frequency of control and allocate the responsibility of that control to a person/function in the organisation.

Definition of the **corrective measures** stating the procedure and responsibility for applying the corrective measure is of course the crucial point in the definition of the whole system. It is not possible to state relevant corrective measures for all the situations that might occur in industries. Annex 2 provides some typical hazards that may occur related to different integrated water treatment processes. The list is not complete and should be seen as a indicate list for inspiration.

[4] Modified from Bent Lyager, University of Southern Denmark (Personal communication)

[5] Modified from Bent Lyager, University of Southern Denmark (Personal communication)

4 Summing up the approach

The core approach of the suggested method is to assess the total water system by a step-by-step check of each use of alternative water qualities including recycled water for unforeseen impacts of the water due to unusual events at the source of the water.

The core of the suggested approach is the identification of Critical Control Points during the three steps outlined below:

Step:	Outcome:
1. Identification of all Potential Critical Control Points (PCCPs) *taking the Water Quality Definition as the starting point - going backwards though the supply system.*	List of PCCPs with indication of process / point of concern and components / limits in focus.
2. Assessment of each PCCP for its use as CCP according to the HACCP principles – in particularly assessment of existence of applicable control method.	List of CCPs with description of point of concern, components / limits in focus and method of control.
3. Describe for each CCP the way of control, the limits to be met and the corrective measures to be applied if abnormal / unforeseen performance is found.	List of CCPs with description of control points and components and limit values, the surveillance/monitoring system and the corrective measures to be applied in case of deviations.

A broader description of the interactions between the different elements of the assessment is illustrated in the Figure 8 below.

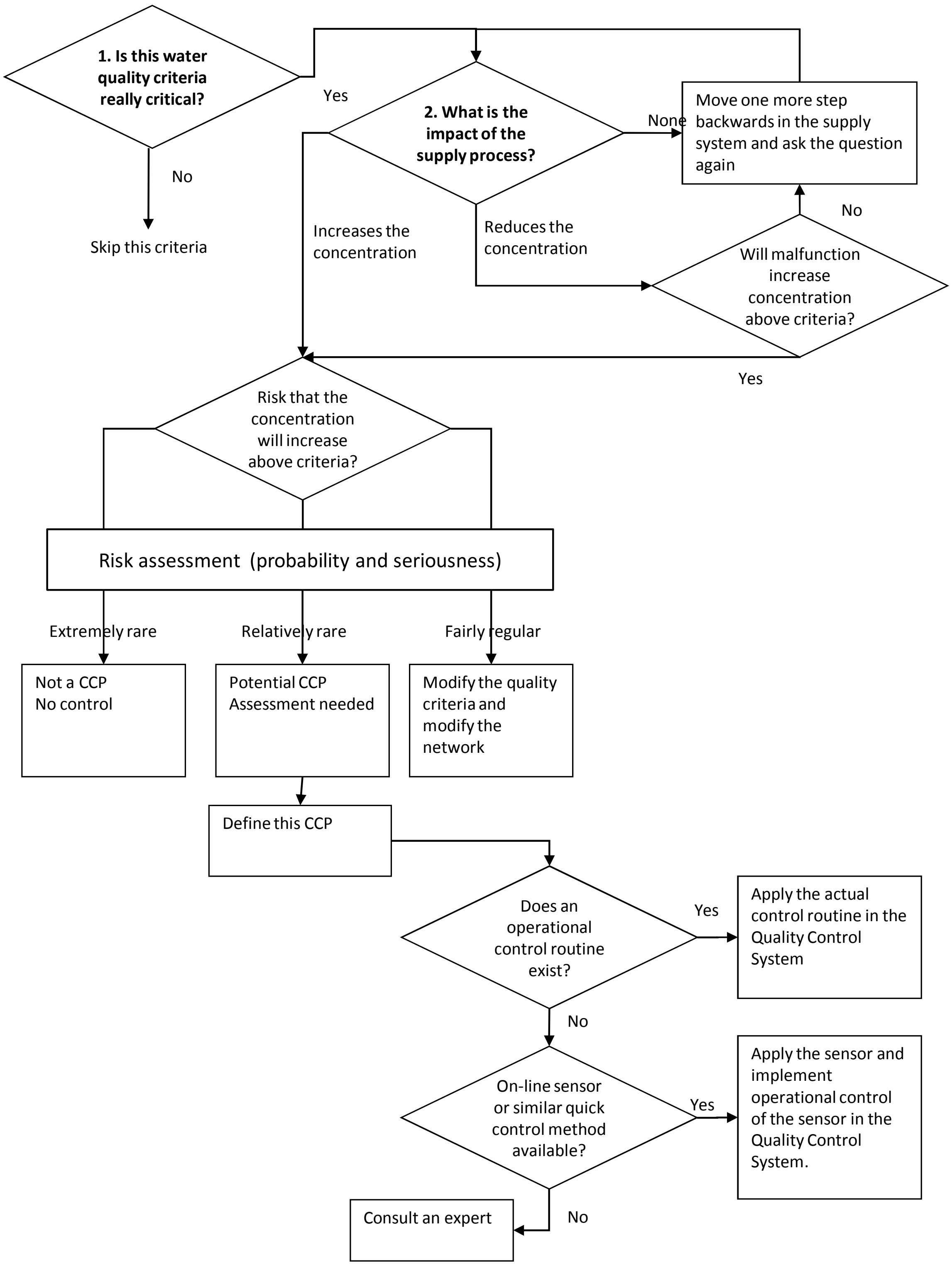


Figure 8 Overall approach to the identification of Critical Control Points in an industrial water network

5 Literature

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6 Annexes

6.1 Annex 1 Typical risks/hazards related to water handling and treatment

(Indicative list)

Process step	Risk factor or potential hazard	Cause	Available measure	Monitoring	Corrective Action
Water intake (tap water)	Deviation from specifications	Problems at delivery company	-	standard	Stop intake
Water intake (surface water)	Deviation from specifications	Calamity	Dilute with other sources	standard	Stop intake
Water buffer	Deviation from specifications	infections	disinfection	turbidity	Stop intake
Production process	Contaminants from raw materials / auxiliary substances	Dirty raw materials	Quality Control raw products	Process	Take care at WWTS
MF/UF	Micro-organisms Too high protein concentration	Leakage membranes	Repair or replace modules	Conductivity, turbidity	
NF	Salts, micro-organisms	Leakage membranes	Replace modules	conductivity	Stop flow
RO	Biofouling	Micro-organisms Availability of nutrients	Cleaning, replace modules	flow	cleaning
Biological treatment (MBR)	Deviation of effluent quality	Failure equipment	Adjust process	pH, conductivity, TOC	adjust
UV-disinfection	Micro-organisms	Failure/run out UV-source	Replace UV-source	Burning time	Replace UV-source
ClO2-dosage	Micro-organisms	Failure dosage	Control and repair	Turbidity	Stop flow
ClO2-dosage	Concentration ClO2 after dosage (residue)	Failure dosage	Control and repair	?	Stop flow

This table has been developed by TNO.

6.2 Annex 2 Monitoring methods for a number of water quality aspects

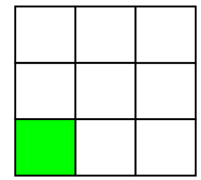
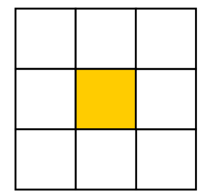
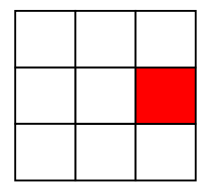
(Indicative examples)

Parameter	Monitoring method	Continuous method	Remarks
Micro-organisms	Turbidity Particle count ATP-measure Plate analysis	Yes Yes Yes No	Not specific, also additional lab analysis Same remark Measures also dead organisms Long response time
Salts	Conductivity Ion selective electrode Chemical analysis	Yes Yes No	Sum parameter
Organic content	TOC COD	Yes No	
Biological activity	O2-measurement Redox-measurement	Yes Yes	For control biological treatment Same remark
pH	pH-sensor	yes	For control - several systems available
Heavy metals	Atomair adsorption Chemical analysis	No No	Lab analysis Lab analysis
Scaling pipes	Pressure drop	Yes	
Colour	Absorption measure DFZ-method	Yes No	 Absorption measure at three different wavelengths

This table has been developed by TNO.

6.3 Annex 3 Identification of Critical Control Points

(With reference to the example explained in the text)

Process	Risk factors	Source	Controlling options	Risk assessment	CCP?
Process 1 receiving water from water supply system	Components / parameters of concern: Colour COD Cadmium Chromium - see limit values in table 3.2.2 – PCCP1	Components controlled at: PCCP1 – the supply of fresh water	It is not possible for the company to impact / control the composition of the water supply. They can only monitor…		CP
Process 1 receiving water from water supply system	Components / parameters of concern: Conductivity Hardness - see limit values in table 3.2.2 – PCCP2	Components controlled at: PCCP2 – the water softening unit	- Regular regeneration - **Control for function of the resins**		CP **CCP 1**
Process 1 receiving water from water supply system	Components / parameters of concern: 'Bacteria' Legionella - see limit values in table 3.2.2 – PCCP2	Components controlled at: PCCP3 – the storage tank for softened water	- Regular emptying of the tank - **Control for Legionella**		CP **CCP2**

6.4 Annex 4 CCP plan

(With reference to the example explained in the text)

CCP no	Risk factors	Source	Controlling options	Critical limits	Surveillance			Corrective measures	
					Procedure	Frequency	Responsibility	Procedure	Responsibility
1	Components / parameters of concern: Hardness of the water	Components controlled at: The water softening unit	Control for function of the resins	Hardness < 100 ppm $CaCO_3$	Sampling and analysis	Every morning	Technician xx	Replacement of ionic exchange resins	Technical department
2	Components / parameters of concern: Legionella	Components controlled at: The storage tank for softened water	Control for Legionella	Not detected	Sampling and analysis	Friday afternoon before emptying the tank	Technician xx	Cleaning of the tank with disinfectant	Technical department