

Challenging drinking water disinfection: How to face up to emerging waterborne pathogens?

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Abstract The disinfection of drinking water remains the primary objective of drinking water treatment. The emergence of new waterborne pathogens has led to a growing need to develop a strategy for reducing the risks of illness. Based on the water safety plan concept, this paper reports on the system assessment, the effective operational monitoring for disinfection and the management plans. The results obtained on the surface water treatment plant of Neuilly-sur-Marne (106 MGD) which includes a full treatment with clarification, ozonation and chlorination, illustrate this paper.

Key words Disinfection, Drinking water, emerging pathogens, HACCP, risk assessment, water safety plan.

Introduction

Working on behalf of the Syndicat des Eaux d'Ile de France (SEDIF), Véolia Water – Compagnie Générale des Eaux operates three major drinking water treatment plants that supply 4 million inhabitants living in the Paris suburbs: Neuilly-sur-Marne, Choisy-le-Roi and Méry-sur-Oise. Almost one million cubic meters of water are produced each day, from the rivers Marne, Seine and Oise respectively. The three resources are contaminated by waterborne pathogens such as *Cryptosporidium* and the raw resource quality is so poor that the emerging pathogens could be present. There is thus a growing need to develop a strategy to reduce the risks of illness from microorganisms and to guarantee disinfection effectiveness. This paper will present the tools used at the Neuilly-sur-Marne surface water treatment plant for addressing these needs.

Background

Infectious diseases caused by pathogenic bacteria, viruses and parasites are the most common and widespread health risk associated with drinking water in the world. To face up to this risk, the latest edition of the World Health Organization (WHO) Guidelines for drinking water quality (WHO, 2004) provides guidance on the development of a Water Safety Plan (WSP). The plan is developed using a water safety framework, which combines HACCP principles with water quality management and the multi-barrier concept. This common framework quantifies hazards or risks within the whole treatment process (up to the point of consumption), and identifies important monitoring and remedial actions at designated hazard control points.

A WSP has three key components, which are guided by health-based targets and overseen through drinking water supply surveillance. These actions, a system assessment, effective

operational monitoring and management, are the responsibility of the drinking water supplier in order to ensure that drinking water is safe. Thus it is necessary to check that these actions are correctly managed.

Illustrations will be given by the surface water treatment plant of Neuilly-sur-Marne for which the nominal flow-rate is 106 MGD. The treatment plant consists of a clarification stage made up of a coagulation/flocculation sedimentation and a rapid sand filtration, an inter-ozonation stage, a refining stage involving biological filtration through Granulated Activated Carbon (GAC) and a final stage of chlorination/dechlorination before distribution into the network.

System assessment

A system assessment is used to determine whether the drinking water supply chain (up to the point of consumption) as a whole can deliver water of a quality that meets health-based targets.

The first information required to answer this question is the source water contamination, which is the first stage of the risk assessment. Then, the required plan performances were analysed with the multi-barrier approach and the quantitative microbial risk assessment.

Source water contamination

In the three surface waters which supply the SEDIF drinking water treatment plants, raw water is influenced by both natural and human factors. Municipal wastewater and livestock to a lesser degree can be a major source of microbial pathogens. Since 1999, *Giardia* and *Cryptosporidium* have been monitored (see Figure 1).

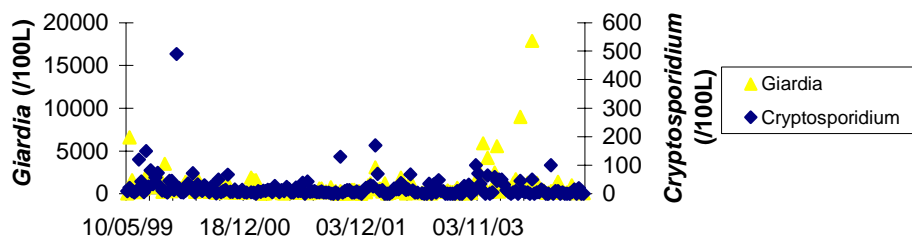


Figure 1 Occurrence of *Giardia* and *Cryptosporidium* in the river Marne

Nevertheless, monitoring is necessary but insufficient. Understanding variations in raw water quality is one of our priorities because such variations affect the treatment efficiency and thus the health risk associated with the finished water. The river's contamination in parasites has been modelled with Spline regression (see Figure 2). This model underlines the concentration of ammonium as an explicative factor of the *Giardia* contamination, which can be explained by the urban sewage as the origin of the presence of *Giardia*. The fact of having high *Giardia* concentration is linked to lashing rainfalls following dry weather. Moreover, there is a seasonal effect: winter is a risky period. For *Cryptosporidium*, results are slightly different: contamination could be due to non-point sources such as agricultural areas.

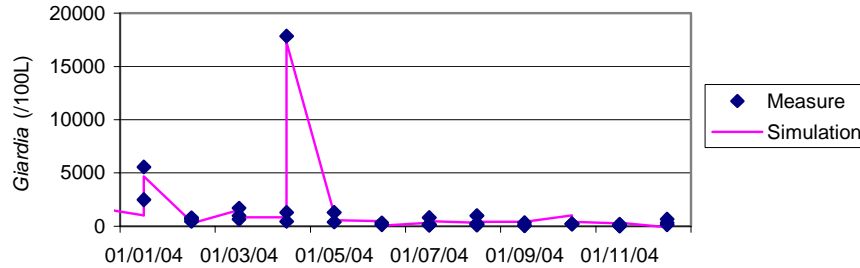


Figure 2 Modelling of *Giardia* concentration in the river Marne by Spline regression

This study will go on to develop a model predicting the parasites concentration in order to be able to adapt the treatment efficiency to the microbial risks.

Multi-barrier concept

The process of providing safe drinking water relied on the application of the multiple barrier concept. These barriers are selected so that the removal capabilities of different steps in the treatment process are duplicated. This approach provides sufficient backup to allow continuous operation in the face of normal fluctuation in performance, which will typically include periods of ineffectiveness.

For the Neuilly-sur-Marne treatment plant, only 2 or 3 steps are efficient for the control of microorganisms: the clarification step from coagulation to sand filtration, the intermediate ozonation step and the final chlorination step with free chlorine. Table 1 sums up the impact of treatment on the microorganisms.

Sand filtration is dedicated to parasite removal, and particularly to *Cryptosporidium* removal.

The main objective of the inter-ozonation stage is water disinfection (viruses and bacteria), even if the ozone disinfection removes more than 6 log units for *Giardia* on which ozone has an impact.

Free chlorine contact times are adequate for the control of 1 to 2 log units of *Giardia* during the worst-case scenario, but it is sufficient to remove bacteria and viruses to a lesser degree.

Table 1 Effectiveness of treatment steps for disinfection (evaluation done in function of the treatment goals of Neuilly-sur-Marne)

		clarification + sand filtration	Ozonation	Chlorination
Parasite	<i>Giardia</i>	+++	+	+
	<i>Cryptosporidium</i>	+++	0	0
Bacteria		0	++	+++
Virus	Poliovirus	0	+++	++
	Hepatitis A	0	+++	++
	Rotavirus	0	+++	++

Table 1 shows where the built-in redundancy occurs. According to the multi-barrier approach, only *Cryptosporidium* is not correctly removed, since only one barrier is available for the elimination. This protozoon was then considered as a reference pathogen for which a quantitative risk assessment was carried out.

Quantitative microbial risk assessment

Moreover, *Cryptosporidium* was shown to be more resistant to disinfectants than previously considered microorganisms and presents significant human health risks. As only one barrier is really efficient to remove this protozoon, the purpose of the risk assessment was to determine the disinfection needs and whether it is necessary to upgrade the plant so that it will meet the health-based targets. Several models can be used to evaluate the health risk.

AFSSA model

In 2002 the French national agency in charge of gathering information on sanitary risks in food (AFSSA) provided a mathematical modelling to estimate the effects of *Cryptosporidium* in drinking water on populations (AFSSA, 2002). The application of this model to the population supplied by the Neuilly-sur-Marne drinking water treatment plant evaluates the risk associated to *Cryptosporidium* as a function of the treatment efficiency (see Figure 3).

Nevertheless, AFSSA did not provide a reference level of risk for *Cryptosporidium*. According to the USEPA, the annual acceptable risk of microbial infection in drinking water is 10^{-4} infections per person (Regli, Rose, *et al.*, 1991). To achieve a level of $<10^{-4}$ per person per year, infectious *Cryptosporidium* oocysts would have to be absent in 290 m³ of drinking water (assuming a 40 % recovery efficiency). With this hypothesis, according to Figure 3, a removal of 3.5 logs of *Cryptosporidium* is necessary.

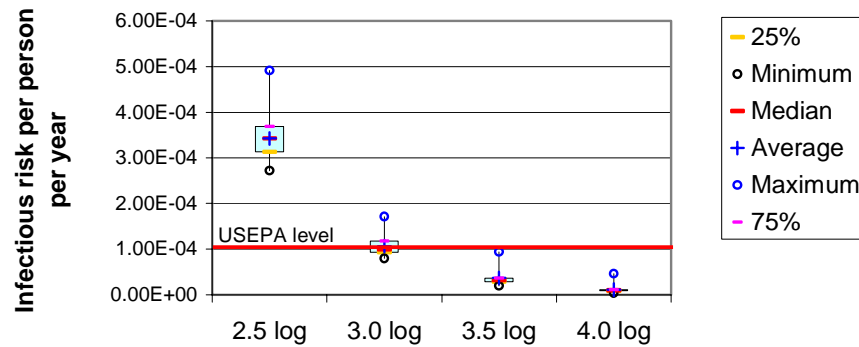


Figure 3 Distribution of infection risk per person per year (AFSSA model) for Neuilly-sur-Marne

The WHO model

According to the WHO guidelines (WHO, 2004), the reference level of risk is 10^{-6} disability-adjusted life-years (DALYs) per person per year, which is approximately equivalent to 1/1000 the annual risk of pathogen causing water disease to an individual – approximately 1/10 over a lifetime.

Application of the WHO leads to a performance target of 3.5 logs for *Cryptosporidium parvum* in relation to the daily consumption of 1 litre of unboiled drinking water to achieve 10^{-6} DALYs per person per year.

Application of the risk assessment

Whatever the model used for the application of the risk assessment, the performance target is 3.5 logs of removal of *Cryptosporidium*. Nevertheless, the efficiency of the *Cryptosporidium*

is essentially due to one step: the clarification and more precisely the sand filtration. Having multiple barriers means that a failure of one barrier can be compensated for by effective operation of the remaining barriers, minimizing the likelihood that contaminants will pass through the treatment system and harm consumers.

A dysfunction of one sand filter, among the 48 filters of the Neuilly-sur-Marne water plant, which was already observed in the past, can lead to 2.1 logs of *Cryptosporidium* removal compared to the 3.5 logs expected for clarification. In the multiple barriers concept, this conventional barrier is thought not to be sufficient and it may be advisable to consider adding multiple stages of filtration or disinfection.

Therefore, according to the risk assessment data and the break-down of where the risk occurs, the SEDIF has decided to strengthen the disinfection by introducing an additional treatment process for *Cryptosporidium* with an UV step.

Effective operational monitoring

To control identified risks and to ensure that the health-based targets are met, control measures must be identified in the drinking water system (the water treatment plant and distribution system). For each control measure identified, an appropriate means of operational monitoring was defined that will ensure that any deviation from required performance is rapidly detected in a timely manner.

Moreover, in France, according to AFSSA, a global analysis must be applied to drinking water quality control, from the resource to the tap. Risks must be identified and critical control points determined in an hazard analysis critical control point (HACCP) approach.

That is why Véolia Eau – Compagnie Générale des Eaux which operates the Neuilly-sur-Marne drinking water treatment plant for the SEDIF determined the key contamination points within the treatment and distribution system through the HACCP.

In the HACCP analysis, several guidelines were established to control the disinfection, requiring continuous monitoring of critical control points (CCP), and systems in place to ensure ongoing control. For each CCP, a set of critical performance level targets was defined.

For the removal of microorganisms, the CCPs are the steps mentioned as disinfection processes in Table 1. Nevertheless, microbial analyses are of limited use in operational monitoring because the time taken to process and analyse water samples does not allow operational adjustments to be made prior to supply. So, for each CCP, effective operational monitoring was chosen among parameters that reflect the effectiveness of the process and can be monitored with sufficient frequency to reveal failures in a timely manner.

Sand filtration

According to the French rules (Code de la Santé Publique, 2003), turbidity has to be lower than 1 FNU at the outlet of the drinking water plant and 2 FNU at the consumer tap whereas the guideline level at the plant effluent is 0.5 FNU. According to the contract between the SEDIF and Véolia Eau, the daily average turbidity has to be lower than 0.1 NTU and the maximum daily value has to be lower than 0.5 at the plant effluent.

To guarantee these values, two parameters are monitored every 2 ½ minutes: these are turbidity and particle count. As there are 48 sand filters in the Neuilly-sur-Marne water treatment plant, measures are done on the combined filter effluent, in order to reduce the amount of measuring equipment.

The turbidity is kept lower than 0.05 NTU and the particle count lower than 200 at the outlet of the sand filtration (see Figure 4 and Figure 5).

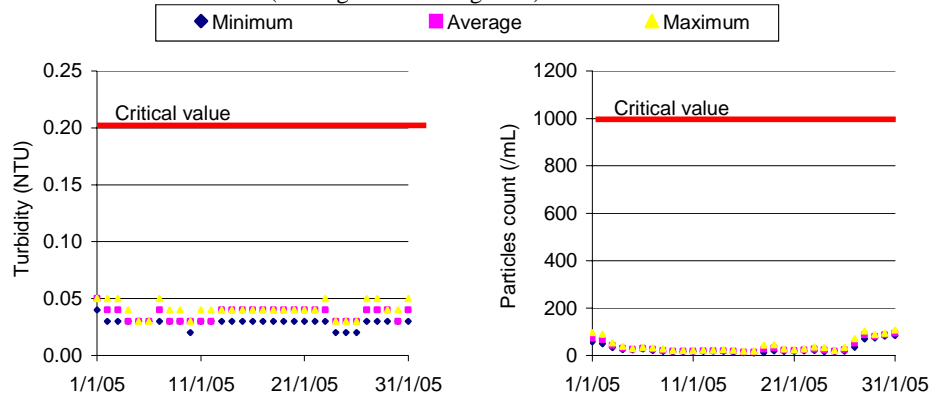


Figure 4 Daily value for turbidity on the combined filter effluent

Figure 5 Daily value for particles on the combined filter effluent

This operating mode is more stringent than the LT2ESWTR compliance requirements (USEPA, 2003) which requires that the combined filter effluent turbidity measurements taken at any month are less than or equal to 0.15 NTU in at least 95 % of the measurements to obtain a 3.5 log *Cryptosporidium* removal credit.

Turbidity and particle counts are the two control measures that indicate the effectiveness of sand filtration with an appropriate frequency to reveal any break-down. They have been chosen to ensure that protozoa removal is achieved.

Ozonation

The intermediate ozonation stage is downstream from the water clarification stage. This step plays a multi-faceted role on the water quality, and primarily water disinfection.

Since 2001, the operation of the ozone units has been based on the ozone efficiency for disinfection, with the Performance Ratio (PR) (Galey, de Traversay, *et al.*, 2004). PR is a ratio between a measured performance and a desired performance for the ozone system. Performances are calculated with the CT concept, as defined by the United States Environmental Protection Agency (USEPA, 1991), which corresponds to the product of the dissolved ozone residual concentration (C) with a contact time (T). The target performance is the CT values from the USEPA tables for 3 logs of *Giardia* inactivation by ozone (Table 1).

Table 2 CT values (mg.min/L) for 3 logs of *Giardia* inactivation by ozone as a function of water temperature (USEPA, 1991)

	Water temperatures (°C)					
	<1°C	5°C	10°C	15°C	20°C	25°C
3 logs	2.9	1.9	1.43	0.95	0.72	0.48

In our multi-barrier treatment strategy, the ozone disinfection is operated to remove more than 6 log units for *Giardia* (with a PR higher than 2). According to the raw water temperature, the minimum CT required for 3 log units for *Giardia* (target performance) is calculated continuously (Table 2) and compared, through the PR, to the CT applied following the ozone residual and the water flow rate at the outlet of each ozonation tank

(measured performance). To guarantee a PR higher than 2, the ozone residual is then adjusted continuously.

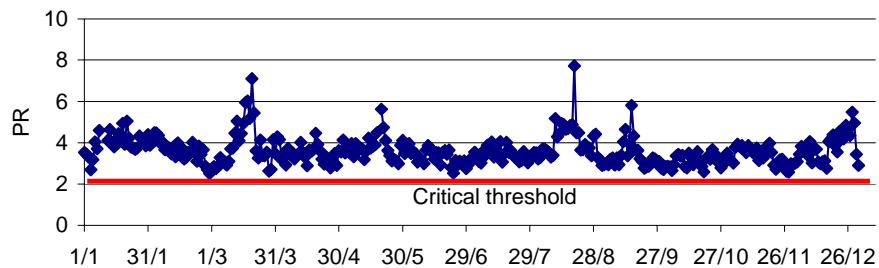


Figure 6 Performance ratio at the Neuilly-sur-Marne utility

The PR is a good tool, which highlights in particular the impact of changes in water flow. It takes the temperature into account. The operators control the PR continuously and can increase it when there is microbiological resource degradation.

Chlorination

Chlorination is operated as a function of the chlorine residual at the outlet of the chlorination tank. This parameter is continuously monitored. The operating threshold is based on the water temperature and the microbiological resource degradation in order to remove bacteria and the distribution into the network is stopped if the chlorine residual is lower than 30 % of the operating threshold. This critical value is defined in the HACCP.

Management

The HACCP plan improved how risks associated with quality water were managed: control measures in the drinking water system (validation) are identified and actions to be taken during normal operation or incident conditions are set out.

For instance, the critical values for sand filtration, defined in the HACCP, for which the distribution into the network is stopped, are 0.2 NFU for the turbidity and 1000 for the particle count. For ozonation, the performance ratio must be higher than 2.

Verification provides a final check on the overall safety of the drinking water supply chain. It includes testing for various microorganisms, in raw water, at different steps during treatment, in treated water and in water in distribution (see Table 3). Finally, more than 20,000 microbial measures were taken, and out of these, 45 % were taken by the surveillance agency. Our own surveillance takes into account the times of increased likelihood of contamination, which can vary according to flooding or a break-down at the sewage plant upstream of Neuilly-sur-Marne.

From a health-related microbiological perspective, the HACCP help us to provide a quality control mechanism to provide consumers with a safe product and add real value to drinking water treatment management.

The HACCP plan is integrated into the management system that links the HACCP with the existing ISO 9001 and ISO 14001 quality systems. Internal and external auditing for quality management systems involves the generation of audit reports, improvement notices and actions.

Table 3 Number of microbial analyses in 2006 for raw water, treated water and water in distribution

	<i>E.coli</i>	Coliforms	Enterococci	aerobic spore-forming bacteria	HPC	Salmonella	Staphylococcus	Enteric virus	<i>Cryptosporidium</i>	<i>Giardia</i>
Regulatory agency										
Raw water	12		12			1				
Treated water	144	144	144	144	144					
Water in distribution	1670	1670	1670	1670	1670					
Our own surveillance										
Raw water	156	156	156	156					52	52
Treated water	260	260	260	260	260	12	12	6	12	12
Water in distribution	1480	1480	1480	1480	1480					

Conclusion

According to this study, controlling the microbiological health risk is linked to the knowledge of microorganisms like the occurrence in the resource or the effectiveness of treatment. Quantitative risk assessment provides the required plant performance and can justify investment to meet the health-based targets. The application of qualitative risk assessment through the HACCP plan provides the critical control points and limits, and helps to define systems to ensure ongoing control with continuous monitoring of critical control points.

All these elements are an illustration of a water safety plan limited to waterborne pathogens.

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