# Norwegian drinking water supply systems and risk management: guidelines, directives and microbial risk assessment

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## Sammendrag

**Norsk drikkevannsforsyning og risiko: Retningslinjer, direktiver og mikrobiologisk risikovurdering.** Overføring av sykdomsfremkallende organismer gjennom drikkevannsforsyningen utgjør en stadig utfordring for folkehelsen i mange utviklede land, inkludert Norge. Det finnes flere forskrifter og retningslinjer som er innrettet mot å redusere forekomsten av vannbårne sykdommer. Disse forskriftene og retningslinjene er basert på bestemte metoder for vannkvalitetsvurderinger og vannforvaltning. Sentralt i disse metodene står helserisikovurderinger, som kan gjøres med kvalitative, semi-kvantitative eller kvantitative metoder. I Norge har kvantitative epidemiologiske metoder vært viktige i forbindelse med helserisikovurderinger. Epidemiologiske metoder er imidlertid sjelden så sensitive at de kan detektere sykdomstilfeller som skyldes de lave konsentrasjonene av sykdomsfremkallende organismer som finnes i drikkevann ved normal drift. De er heller ikke egnet til hurtig å gi informasjon om smitteutbredelsen i en befolkning ved tilfeller av alvorlige negative hendelser i befolkningens vannforsyningssystem. I denne artikkelen foreslås det å ta i bruk kvantitativ mikrobiell risikovurdering (QMRA) som grunnlag for å håndtere risiko, og da som et utfyllende element til eksisterende forskrifter og retningslinjer. Det demonstreres hvordan en enkel QMRA kan implementeres for å besvare bestemte spørsmål rundt risikohåndtering som opptar den som drifter et vannverk. Det blir pekt på noen utfordringer som trolig vil oppstå ved implementering av QMRA for risikohåndtering i norske vannverk, og det gis til slutt noen anbefalinger til hvordan slike utfordringer kan møtes.

## Abstract

The transmission of pathogenic organisms through drinking water supply systems remains a significant public health challenge in many developed countries including Norway. There exist a number of guidelines and directives formulated to reduce the incidence of water borne diseases. These guidelines and directives are implemented and verified through a water quality assessment and management framework. At the heart of the framework is health risk assessment. Health risk assessment may be conducted using qualitative, semi-quantitative or quantitative approaches. In Norway, quantitative epidemiological methods have been integral in the health risk assessment component of the water quality assessment and management framework. However, epidemiological methods are not often sensitive enough to detect disease cases associated with low concentration of pathogens in water supply systems; nor are they able to provide a rapid feedback on public health status during hazardous events in water supply systems. This paper suggests the use of quantitative microbial risk assessment (QMRA) as a complement to existing guidelines and directives for risk management decisions in Norwegian water supply systems. The paper demonstrates how a simple QMRA can be implemented to address specific risk management questions that managers of a water supply system may face. Challenges likely to be encountered in the implementation of QMRA for risk management in water supply systems in Norway are outlined; and some recommendations for overcoming these challenges are presented.

Key words: Guidelines, Risk Management, Risk Assessment, Quantitative Microbial Risk Assessment

## Introduction

The primary objective of a drinking water supply system is to provide water that is bereft of chemical and microbial contaminants that can adversely affect public health. However, meeting this objective remains an on-going challenge in many regions of the world. Worldwide, 1.7 million deaths are attributed to diseases directly associated with failures of drinking water supply systems (WHO, 2004). While chemical contaminants can lead to significant health risks, microbial pathogens remain, by far, the most important health hazard in drinking water supply systems. All pathogens of viral, bacterial, parasitic and protozoan origins can be transmitted through drinking water and lead to disease outbreaks. Advances in water treatment technologies combined with effective health management systems have significantly reduced the frequency of occurrence and severity of waterborne disease outbreaks, particularly in developed countries. Nevertheless, waterborne disease outbreaks still remain a major public health concern in these countries. Between 2000 and 2007, 354 waterborne disease outbreaks were recorded in 14 countries in the United Nations Economic Commission of Europe (UNECE) region[1], resulting in over 47 617 episodes of illnesses (WHO-Europe, 2009). This is only a tip of the iceberg as most waterborne disease cases go unreported. The region has also experienced some major waterborne disease outbreaks. Notable among these outbreaks include the *Cryptosporidium* outbreak in the United States (Mac Kenzie *et al.* 1994) and Sweden (ECDC, 2011); the *E.coli* O157:H7 outbreak in Canada (Hrudey *et al.* 2003); and the *Giardia* outbreak in Norway (Nygård *et al.* 2006). Since the waterborne *Giardiasis* outbreak in Norway, there have been other waterborne disease outbreaks in the country but of relatively less public health impact (Jakopanec *et al.* 2008).

Key lessons gleaned from the above outbreaks include a) the vulnerability of water treatment processes to persistent pathogens; b) weaknesses in risk management systems to detect and respond to vulnerabilities in water supply systems; and c) inadequacies in existing surveillance methods to rapidly assess the impact of water supply systems on public health and rapidly notify water supply system managers. In the coming years, these challenges have to be addressed if water supply systems are to adequately protect human health. This is particularly so as in the coming decades, water supply systems will be significantly challenged by a number of factors. One of the biggest challenges water treat-

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[1] The United Nations Economic Commission for Europe (UNECE) was established in 1947 to encourage economic cooperation among its member states. It has 56 member states. As well as countries in Europe, it includes Canada, the Central Asian republics, Israel and the United States of America.

ment plants will face will be the resurgence and emergence of known and unknown pathogens with high resistance to current water treatment processes (OECD and WHO, 2003). Also, rapid changes in pathogen load in raw water sources due to extreme weather conditions will significantly challenge the ability of water supply systems to supply safe drinking water. The capacity of water supply systems managers to mitigate the health impacts of these challenges will be dependent on their ability to predict, characterize and account for hazardous and non-hazardous events in the water supply system within an overall risk management framework. More importantly, legislative instruments and operational guidelines that provide the enabling environment for water supply managers to undertake risk management tasks will be very crucial. This paper gives a brief overview of the existing international and national guidelines relevant for the management of health risk in Norwegian water supply systems. Risk assessment approaches (including Quantitative Microbial Risk Assessment) used in the assessment and management of health risk in water supply systems are presented and their strengths and weaknesses expounded. Finally, a hypothetical example on the application of Quantitative Microbial risk Assessment for the assessment and management of *Campylobacter* infection risk is presented.

## Guidelines for Drinking Water Quality and Risk Management in Norway

There exist a number of international guidelines and directives on drinking water that are of relevance to Norwegian water supply systems. These guidelines include European Water Directive Framework (Council Directive 98/83/EC), UNECE Water and Health Protocol (UNECE, 1999), and WHO drinking water quality guideline (WHO, 2004). These directives and guidelines are intended to support the development and implementation of risk management strategies that will ensure the safety of drinking-water supplies through the control of hazardous constituents of water. The primary purpose of the WHO *Guidelines for Drinking-water Quality* is the protection of public health (WHO, 2004). The European Water Directive Framework is also formulated to "protect human health from the adverse effects of any contamination of water intended for human consumption by ensuring that it is wholesome and clean" (Council Directive 98/83/EC). Similarly, the UNECE Protocol has the cardinal objective "to promote at all appropriate levels, nationally as well as in transboundary and international contexts, the protection of human health and well-being, both individual and collective, within a framework of sustainable development, through improving water management, including the protection of water ecosystems, and through preventing, controlling and reducing water related diseases" (UNECE, 1999).

The WHO guidelines set specific minimum quality parameters and values for both microbial and chemical contaminants in drinking water that should be achieved by water supply systems to consider the water as acceptable for human consumption (WHO, 2004). Both the UNECE and EU Water Directive Framework mandate their member states to ensure that their water supply systems provide water that meet the minimum quality parameters and values set by WHO. In addition, the EU Water Directive Framework makes provision for member states to consider other water quality parameters based on the opinion of the Commission Scientific Advisory Committee. To ensure that member states are meeting the targets for drinking water quality, the UNECE Protocol on Water and Health further mandates member states to "… establish and publish national and/or local targets for the standard and levels of performance to be achieved or maintained for high level of protection against water-related diseases".

In Norway, the Norwegian Drinking Water Regulations (*Drikkevannsforskriften*) (NDWR) sets the framework for drinking water quality guidelines. The regulation has the avowed objective of ensuring that water supply systems in the country, provide drinking water in adequate quantities and of a satisfactory quality, including ensuring that drinking water does not contain contaminants of any kind" (Mattilsynet, 2011). Specific minimum values for microbial and chemical substances in drinking water are set out in the NDWR. These minimum quality parameters and values are not significantly different from those set in the WHO *Guidelines for Drinking Water Quality*. Consequently, NDWR is also in synch with the EU and UNECE drinking water quality directives. NDWR further adopts the WHO multi-barrier approach to risk management in water supply systems by providing that all water supply systems should have at least two barriers against pathogenic organisms of public health concern. The actualization of the minimum guideline values of the NDWR in Norwegian water supply systems is operationalized partly through an Optimal Disinfection Practice for drinking water (*Optimal Disinfeksjons-praksis for Drikkevann)* (Norsk Vann, 2009). ODP is tailored towards enhancing the capacity of operators/managers of water supply systems to plan, design and operate water systems to safeguard public health. Specifically, the key objectives of ODP are:

a) to assist officers in drinking water management to determine whether proposed or planned disinfection measures are sufficient- in dialogue with waterworks victory and their advisors;
b) to assist waterworks owners and planners to identify which disinfection should be put into a planned or existing waterworks to ensure a sound barrier level;
c) to help planners and advisors with methods that can be used to analyze and design disinfection measures so that they provide the inactivation levels that good disinfection practice should achieve a given case; and
d) to assist operator of disinfection facilities to conduct their disinfection measures so that they provide the inactivation extent that good disinfection practice should achieve in a given case

The ODP sets out a comprehensive health risk management framework that defines the disinfection required by a water treatment plant for pathogenic organisms of public health concern. The health risk management framework is based on a log-credit system. Thus water is considered safe for human consumption for specific pathogenic organisms under a given scenario if existing disinfection processes in the water treatment plant achieve specific log-credits. The ODP risk management framework is also in synch with the WHO water safety planning (WSP) approach, which is designed to ensure safe drinking water through enhanced risk assessment and management system (Bartram *et al.* 2009). WSPs require the conduct of risk assessment as an input to risk management decisions in water supply systems.

## Water Safety Planning and Health Risk Assessment

The Water Safety Planning (WSP) approach has been implemented by managers of large and small water supply systems to mitigate health risks in both developed and developing countries. WSP is an iterative approach to risk management that is underpinned by the Water Quality Assessment and Management Framework, figure 1.

At the heart of the framework is the setting of health based targets that a water supply system has to achieve to be considered safe. In essence, "health-based targets underpin the development of WSPs, as they provide information with which to evaluate the adequacy of existing installations and assist in identifying the level and type of inspection and analytical verifications that are appropriate" (WHO, 2004). There are four main health based targets that can be set for a water supply system- *health outcome targets; water quality targets; performance targets; and technology targets*. These targets have to be set based on a rigorous risk assessment taking into account the background health status of the population that depend on the water supply system, figure 1.

In Norway, water quality targets are set for microbial pathogens (mainly indicator organisms) and chemicals (Mattilsynet, 2011); and disinfection (performance and technology) targets for achieving these water quality targets are expounded in the ODPs on the basis of a log-

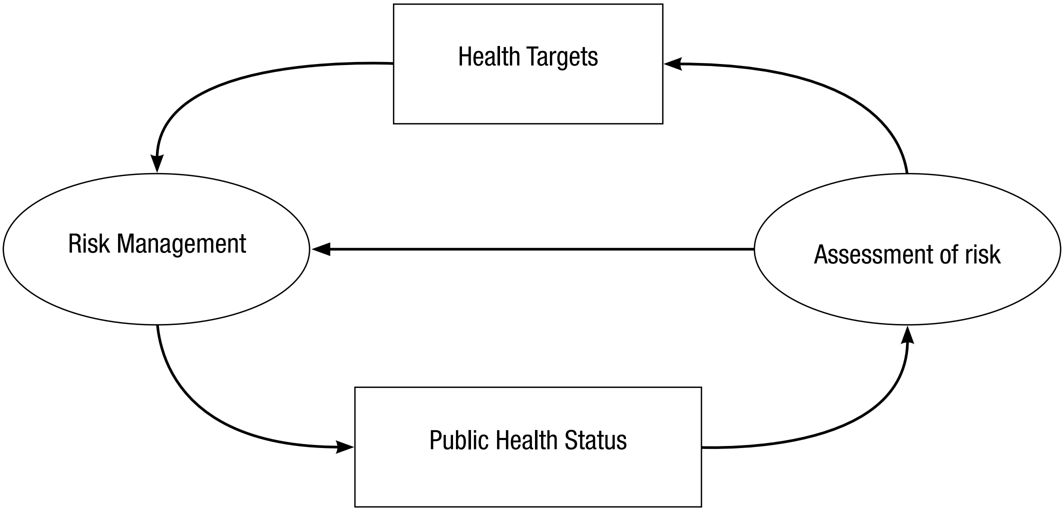


*Figure 1. Water Quality Assessment and Management (Adapted from Fewtrell & Bartram (2001).*

credit system (Norsk Vann 2009). Neither the drinking water quality guidelines nor the ODPs are further linked to specific public health status of the population served by water supply systems. Indeed, in Norway, the exact contribution of the water quality guidelines in combination with the disinfection practices on overall public health status is not known. This is only verifiable through a comprehensive health risk assessment to determine whether the existing risk management practices adequately safeguards consumers' health or not.

The WHO water safety plan manual presents qualitative and quantitative risk assessment approaches that can be implemented by a water supply system to aid specific risk management decisions. In the continuum of the qualitative to quantitative approaches lies the semi-quantitative approach. While qualitative health risk assessment approaches are based on decision intuition, quantitative health risk assessment approaches are based on decision analysis. In qualitative risk assessment, "hazards and hazardous events that can compromise the quality of drinking water are prioritized based on a team's judgement and historical experience".

The significance of each hazard and hazardous event is then considered in relation to how likely it will occur and the impact on public health taking into account existing barriers in the water supply system. The hazardous events are simply listed and ranked. The semi-quantitative approach, is a two-step process, it involves the assessment of the likelihood of occurrence of the hazardous events and the consequence or severity of the impact of the event on public health. Each event is then mapped in a matrix to get a risk ranking. For details on how to conduct qualitative and semi-quantitative risk assessment for a water supply system readers are referred to the Water Safety Plan Manual (Bartram *et al.* 2009).

Both the qualitative and semi-quantitative approaches to risk assessment are ridden by a high degree of subjectivity. The outcome of the risk assessment is highly dependent on the experience of the team members on specific treatment processes in relation to hazardous events; and of their knowledge on the impact of the event on public health. In the absence of a comprehensive manual to rank different hazardous events as is the case in Norway, the qualitative and semi-quantitative approaches could lead to significantly disparate risk assessment outcomes even for water supply systems with the same treatment processes, and raw water source.

Quantitative risk assessment approaches that are currently used to quantify the public health impact of water supply systems are epidemiological and quantitative microbial risk assessment (QMRA). While the former has for several decades been the main health risk assessment vehicle in water supply systems, the application of QMRA in health risk assessment in water supply systems is more recent.

In Norway, and in many countries, the public health impact in relation to water supply systems is still verified through epidemiological methods. However, pathogens in drinking water often occur in extremely low concentrations; and current epidemiological tools are often not sensitive enough to detect a few cases associated with such low concentrations (Eisenberg *et al.* 2002). Current epidemiological surveillance methods are also not able to detect outbreaks with the rapidity needed to reduce the burden of disease during severe hazardous events in water supply systems.

A notable example is the Milwaukee outbreak, which was not recognized for some days until there was widespread absence among hospital employees, students, and school teachers, increased numbers of emergency room visits for diarrhoeal disease illness, and shortage of antidiarrhoeal drugs (Kramer *et al.* 1996). Worse still, the etiological agent and the waterborne nature of the outbreak were not identified until at least two weeks after the onset of the outbreak. Thus, water boiling order during the Milwaukee outbreak was issued after several people had been infected. Similar observations were made in relation to the *Giardiasis* waterborne outbreak in Bergen where high cases recorded by medical doctors provided the signal for an epidemiological investigation that eventually implicated the water supply system (Nygård *et al.* 2006). Unlike epidemiological methods, QMRA allows for the assessment of health risk at extremely low concentrations of pathogenic organisms thereby accounting for non-outbreak cases and early identification of outbreak cases. Also, as QMRA allows for disease cases to be estimated using mathematical models, more rapid results can be obtained for a rapid response to hazardous events in the water supply system. Seidu *et al.* (2007) presented a conceptual framework for incorporating QMRA into the management of health risks in water supply systems in Norway.

More information on the specific steps in QMRA in relation to water supply systems can be found in Seidu *et al.* (2007) and WHO (2004). Generally, QMRA involves four interlinked steps- hazard identification, exposure assessment, dose-response assessment and risk characterization (Haas *et al.* 1999). Hazard assessment involves identification of pathogenic organisms in the water supply system as well as the range of diseases they cause. Exposure assessment involves a determination of the size and nature of the population connected to the water supply system; and the amount and duration they are exposed to pathogenic organisms from the water supply system. Dose-response assessment describes the relationship between the dose of pathogens from the water supply system potentially ingested and the probability of infection. Risk characterization combines information from all the steps to estimate the likelihood of infection.

Since Seidu *et al* (2007) publication, very little work has been done on the implementation of QMRA in Norwegian water supply systems. QMRA can be a useful tool in the management of microbial health risks arising from water supply systems in Norway. The approach has been integrated into risk management strategies in water supply systems in several UNECE countries including the United States, Sweden, and the Netherlands. There are several key risk management questions that can be addressed quantitatively using QMRA.

Among others, the following questions can be addressed by water supply managers using QMRA: a) Is the water supply system performance meeting health targets?; b) What are the priority microbial hazards for the water supply system?; c) what is the public health significance of hazardous events?; d) is the overall treatment adequate to produce drinking water that meets the health target? e) What are appropriate critical limits?; f) how much monitoring is necessary?; g) what level of corrective actions is needed?; and h) What is the cost-effectiveness of introducing a new treatment barrier or upgrading an existing one? In the next section, the application of QMRA in addressing some key risk management questions in a water supply system is demonstrated. The data used in the assessment are fictitious and should not be interpreted in relation to any existing water supply system.

## Application of QMRA in estimating Campylobacter infection cases and identifying critical control points in a water supply system

A water supply system (WSS) supplies treated water to 400,000 people. The WSS depends on a surface water body as its main raw water source; and has flocculation/coagulation, granular activated carbon (GAC), UV (30-40mWs/cm$^2$), and chlorine as the main treatment steps, figure 2. The daily cold water consumption of the population depending on the WSS is 0.95 L(Westrell *et al.* 2004).

Monitoring of the raw water source shows an average daily *Campylobacter jejuni* concentration of 70/100 mL (Westrell *et al.* 2004). It is assumed that the method used for the detection of *Campylobacter jejuni* in the raw water source achieves 100% recovery rate. The effectiveness of Flocculation/Coagulation, GAC, UV and Chlorine against *Campylobacter jejuni* is conservatively estimated to be 0.5 log; 0.3 log; 6.5 log and 2.5 log respectively (Westrell *et al.* 2004).

The managers of the WSS will be interested in finding answers to the following likely non-hazardous and hazardous events: 1) how many *Camylobacter jejuni* infections will be recorded annually in the population given the existing treatment barriers of the WSS? 2) how many people will be infected if there is a failure in the UV disinfection step or both the UV and chlorine disinfection steps; 3) how many people will be infected if there is a sudden increase in the concentration of *Campylobacter jejuni* to 7 x 10$^6$ per 100mL in the raw water source as a result of discharges from wastewater treatment plants or other non-point sources for a period of 5 days? 4.) How many people will be infected if this sudden increase is combined with failure of one or more of the most effective barrier against *Campylobacter jejuni* in the water treatment train? These questions can be addressed using QMRA. The step-wise approach to these questions using QMRA is presented below:

Assuming a complete dispersion of *Campylobacter jejuni* in the raw water source and in treated water, the dose (*d*) of *Campylobacter* ingested is given as:

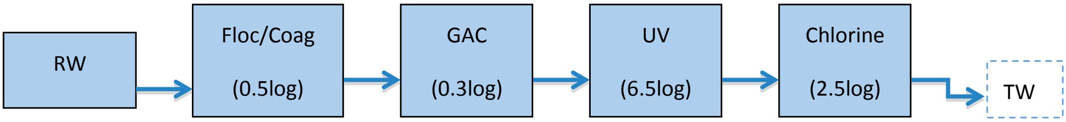
$$d = c \text{ x } V \text{ x } 10^{-Lr} \text{ ...... } \textit{Eqn. 1}$$

Where *c* is the concentration of *Campylobacter jejuni* in the raw water source during normal or hazardous events; *V* is the daily amount of cold water consumed on the event or non-event days (i.e. 0.95L per person per day); and *Lr* is the total log reduction achieved by the different treatment steps in the water supply system.

The infection risk associated with the ingestion of *Campylobacter* can be described by the beta-Poisson dose response model (Haas *et al. 1999*), which is given as:

$$P_i = 1 - \left[1 + \left(\frac{d}{N_{50}}\right)\left(2^{1/\alpha} - 1\right)\right]^{-\alpha} \text{ ...... } \textit{Eqn. 2}$$

Where *Pi* is the probability of *Campylobacter jejuni* infection; *d* is the dose of *Campylobacter jejuni* ingested as defined in *Eqn. 1*; $N_{50}$ is the median infection dose and α is the dimension-



RW= raw water source; Floc/Coag= Flocculation/Coagulation; GAC= Granular Activated Carbon; TW= treated water

*Figure 2. Water supply system.*

less infectivity constant. For *Campylobacter jejuni* α and $N_{50}$ are estimated to be 0.145 and 896 (Haas *et al.* 1999).

The infection risk associated with multiple exposures to *Campylobacter jejuni* can be expressed as:

$$P_m = 1 - (1 - P_i)^n \text{.........} Eqn.\ 3$$

Where $P_m$ is the probability of infection associated with multiple exposure; $P_i$ is as defined in eqn. 2 and *n* is the number of days of hazardous or non-hazardous events. Eqn. 3 can be expanded to account for both hazardous and non-hazardous event in the water supply system as follows:

$$P_m = 1 - (1 - P_{i1})^{n1\,(non\text{-}event)}\, x\, (1 - P_{i2})^{n2\ (event)} \quad \text{......}\ Eqn.\ 4$$

Where $P_m$ is as defined in *Eqn.3;* $P_{i1}$ and $P_{i2}$ is the probability of infection as defined in Eqn 2. for non-hazardous and hazardous events respectively in the water supply system; and *n1* and *n2* is the number of non-hazardous and hazardous event days in the water supply system.

The number of people infected given an event or non-event situation is given as:

$$P_n = P_m\, x\ 400{,}000 \ \text{........}\ Eqn.5$$

From the above formulations, the daily ($P_i$) and multiple exposure ($P_m$) *Campylobacter* infection risks associated with the event and non-event scenarios in the water supply system can be obtained for risk management decisions. The results for each of the scenarios are presented in table 1 below. It should be noted that the results presented in table 1 are only deterministic (i.e. point estimates). A stochastic model can be implemented where all the inputs for the risk assessment model are described by probability distribution functions to account for both variability and uncertainty in the results. However, it is always advisable for a simple deterministic risk assessment to be conducted before a more complex stochastic model is conducted if necessary.

Table 1 shows that approximately 1 person is at risk of infection annually if all the treatment barriers are functioning and the average daily concentration of *Compylobacter jejuni* remains at 70/100 mL in the raw water. In the event of failure of the UV disinfection step for a period of 5 days, 12000 persons are likely to be infected with *Campylobacter jejuni*. Also, should the UV and chlorine disinfection steps fail for 5 days; the number of people likely to be infected will be 340000. Given that all the treatment barriers are functioning as expected, the number of people likely to be infected with *Campylobacter* in the event of a sudden increase in the concentration

| Scenario | $P_i$ | $P_m$ | No. of consumers infected |
|---|---|---|---|
| 1. Normal operational conditions | $2 \times 10^{-9}$ | $7.4 \times 10^{-7}$ | ~ 1 person infected in a year (365 days) |
| 2a. Failure of UV during normal situation (70/100mL) | $6.2 \times 10^{-3}$ | $3.0 \times 10^{-2}$ | 12000 persons infected during 5 days of UV failure only |
| 2b. Failure of UV and chlorine during normal situation (70/100mL) | $3.2 \times 10^{-1}$ | $8.5 \times 10^{-1}$ | 340000 persons infected during 5 days of UV and Chlorine Failure |
| 3. Sudden increase in the concentration of *Campylobacter* by 100000 folds. | $2 \times 10^{-4}$ | $1.0 \times 10^{-3}$ | 400 persons infected during 5 days of sudden deterioration of raw water quality |
| 4a.Failure of UV disinfection step during 5 day sudden increase in *Campylobacter* concentration | $7.0 \times 10^{-1}$ | $9.9 \times 10^{-1}$ | Almost all consumers are likely to be infected during 5 days of exposure |
| 4b.Failure of UV and chlorine during 5 day sudden increase in *Campylobacter* concentration | $8.7 \times 10^{-1}$ | ~ 1 | Almost all are likely to be infected during 5 days of exposure |

*Table 1. Campylobacter jejuni infection risk and number of cases associated with different event and non-event scenarios in a water supply system.*

of *Campylobacter* in the raw water from 70/100mL to 7 x $10^6$/100mL would be 400 persons.

Failure in the UV disinfection step only or both the UV and Chlorine disinfection steps would result in *Campylobacter* infection in nearly all the population connected to the WSS. These results can be expanded further in a QMRA framework to account for the number of illnesses and disease burden for the society associated with the different events for effective risk management decisions. Cost elements can also be introduced for different treatment processes (eg. chlorine and UV disinfection) to ascertain whether it is worth upgrading or investing in such interventions. Overall, the above example demonstrates that QMRA provides an objectively quantifiable step- by step approach for the conduct of microbial health risk assessment that can be verified and validated through rigorous quality assurance processes. Thus, the approach allows for rational and factually based risk management strategies/interventions in relation to drinking water supplies. However, the full integration of QMRA for health risk management in water supply systems is not without challenges. A few of the challenges that are likely to be faced in the application of QMRA in water supply systems in Norway are:

a) The lack or inadequacy of extensive data on variations in pathogenic organisms in raw water sources;
b) Inadequate data on exposure scenarios (i.e. amount of water consumed as disaggregated by age-group); dose-response models; frequency of occurrence of hazardous events (ie. failures or sub-optimum performance of specific chemical and biological treatment steps);
c) Inadequate capacity to undertake risk assessment using QMRA. Many water supply systems do not have staff with the capacity to conduct risk assessment using QMRA approaches. Worse still, the study curricular for water and wastewater engineers does not consider microbial risk assessment as an important component of their curricular. The most recently published text book for water and wastewater engineering students in Norway does not succinctly capture risk assessment as a potential tool that can be incorporated into the design of wastewater and/or water treatment plants.

## Conclusions and Recommendations

The transmission of pathogenic organisms through drinking water supply systems remains a significant public health challenge in many developed countries including Norway. There exist a number of guidelines and directives formulated to reduce the incidence of water borne diseases. These guidelines and directives have to be implemented and verified through a water quality assessment and management framework. At the heart of the framework is health risk assessment. Health risk assessment may be conducted using qualitative, semi-quantitative and quantitative approaches. In Norway, epidemiological methods have been integral in the health risk assessment component of the framework. However, epidemiological methods are not sensitive enough to detect disease cases associated with low concentration of pathogens in the water supply system; nor are they able to provide a rapid feedback on public health status to water supply managers in the event of a hazardous event in the water supply system. This paper has shown that QMRA can be implemented to assess health risk associated with events and non-events scenarios. However, the implementation of QMRA in Norwegian water supply systems can be challenging. It is recommended that:

a) Studies are conducted to better characterize the input variables for quantitative microbial risk assessment for Norwegian water supply systems;
b) Existing guidelines and directives on drinking water are extended to encapsulate specific health outcome targets;
c) A manual should be prepared for a clear step-by-step guidance on the conduct of both microbial (and chemical) quantitative risk assessment for water supply systems;

and

d) Water supply system managers should build the capacity of their core staff responsible for risk management decision to conduct quantitative microbial risk assessment.

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## Abbreviations

**ECDC**- European Center for Disease Control
**GAC**- Granular Activated Carbon
**NDRW**- Norwegian Drinking Water Regulations
**OECD**- Organization for Economic Co-operation and Development
**QMRA**- Quantitative Microbial Risk Assessment
**UNECE**- United Nations Economic Commission for Europe
**UV**- Ultra Violet
**WHO**- World Health Organization
**WSP**- Water Safety Plan
**WSS**- Water Supply System

## References

Bartram, J., Corrales, L., Davison, A., Deere, D., Drury, D., Gordon, B., Howard, G., Rinehold, A. and Stevens, M. (2009) Water Safety Plan manual: step-by-step risk management for drinking water suppliers. WHO, Geneva.

ECDC(2011). Cryptosporidium outbreak in Sweden http://ecdc.europa.eu/en/activities/sciadvice/Lists/ECDC%20Reviews/ECDC_DispFm.aspx?ID=1047 (Accessed on 25.08.2013)

Eisenberg, J. N., Brookhart, M. A., Rice, G., Brown, M. and Colford, J. M., Jr. (2002). Disease transmission models for public health decision making: analysis of epidemic and endemic conditions caused by waterborne pathogens. *Environmental Health Perspectives* 110(8): 783-790.

Haas, C. N., Rose, J. B. and Gerba, C. P. (1999). Quantitative microbial risk assessment. New York, John Wiley & Sons, Inc.

Hrudey, S. E., Payment, P., Huck, P. M., Gillham, R. W. and Hrudey, E. J. (2003). A fatal waterborne disease epidemic in Walkerton, Ontario: comparison with other waterborne outbreaks in the developed world. *Water Science and Technology* 47(3): 7 14.

Jakopanec, I., Borgen, K., Vold, L., Lund, H., Forseth, T., Hannula, R. and Nygård, K. (2008). A large waterborne outbreak of campylobacteriosis in Norway: The need to focus on distribution system safety. *BMC Infect Dis.* 8: 128.

Kramer, M. H., Herwaldt, B. L., Craun, G. F., Calderon, R. L. and Juranek, D. D. (1996). Surveillance for waterborne-disease outbreaks – United States, 1993-1994. *MMWR Surveillance Summaries* 45(1): 1-33.

Mac Kenzie, W. R., Hoxie, N. J., Proctor, M. E., Gradus, M. S., Blair, K. A., Peterson, D. E., Kazmierczak, J. J., Addiss, D. G., Fox, K. R., Rose, J. B. and Davis, J. P. (1994). A massive outbreak in Milwaukee of *Cryptosporidium* infection transmitted through the public water supply. *New England Journal of Medicine* 331(3): 161-167.

Mattilsynet (2011). Veiledning til Drikkevannsforskriften. Brumunddal..

Norsk Vann (2009) Optimal disinfeksjonspraksis fase 2. Norsk Vann Rapport 169/2009. Hamar.

Nygård, K., Schimmer, B., Søbstad, Ø., Walde, A., Tveit, I., Langeland, N., Hausken, T. and Aavitsland, P. 2006 A large community outbreak of waterborne giardiasis-delayed detection in a non-endemic urban area. *BMC Public Health,* 6: 141.

OECD & WHO (2003). Assessing Microbial Safety of Drinking Water: Improving Approaches and Methods. IWA Publishing London.

Seidu, R., Heistad, A., Lindholm, O., Vrale, L., Jenssen, P.D. and Stenstrøm, T.A. (2007). Integrating Quantitative Microbial Risk Assessment into Health Risk Management of Water Supply Systems in Norway**.** *Vann Nr. 4.*

Westrell, T. (2004) Microbial Risk Assessment and Its Implications for risk management in urban water systems. Phd Thesis. Linkoping University, Sweden.

WHO (2004). Guidelines for Drinking Water Quality, 3rd edition. Geneva, World Health Organization.

WHO-Europe .(2009). Outbreaks of Waterborne Diseases. Fact Sheet 1.1. December 2009. http://www.euro.who.int/__data/assets/pdf_file/0009/96885/1.1.-Outbreaks-of waterborne-diseases-EDITED_layout_V03.pdf (accessed on 24.08.2013)

UNECE (1999). Protocol on Water and Health to the 1992 Convention on the Protection and Use of Transboundary Watercourses and International Lakes.Second Meeting of the Parties to the Protection and Use of Transboundary Watercourses and International Lakes, The Hague, Netherlands, 23–25 March 2000.